New Scientist

WEEKLY 18 February 2023

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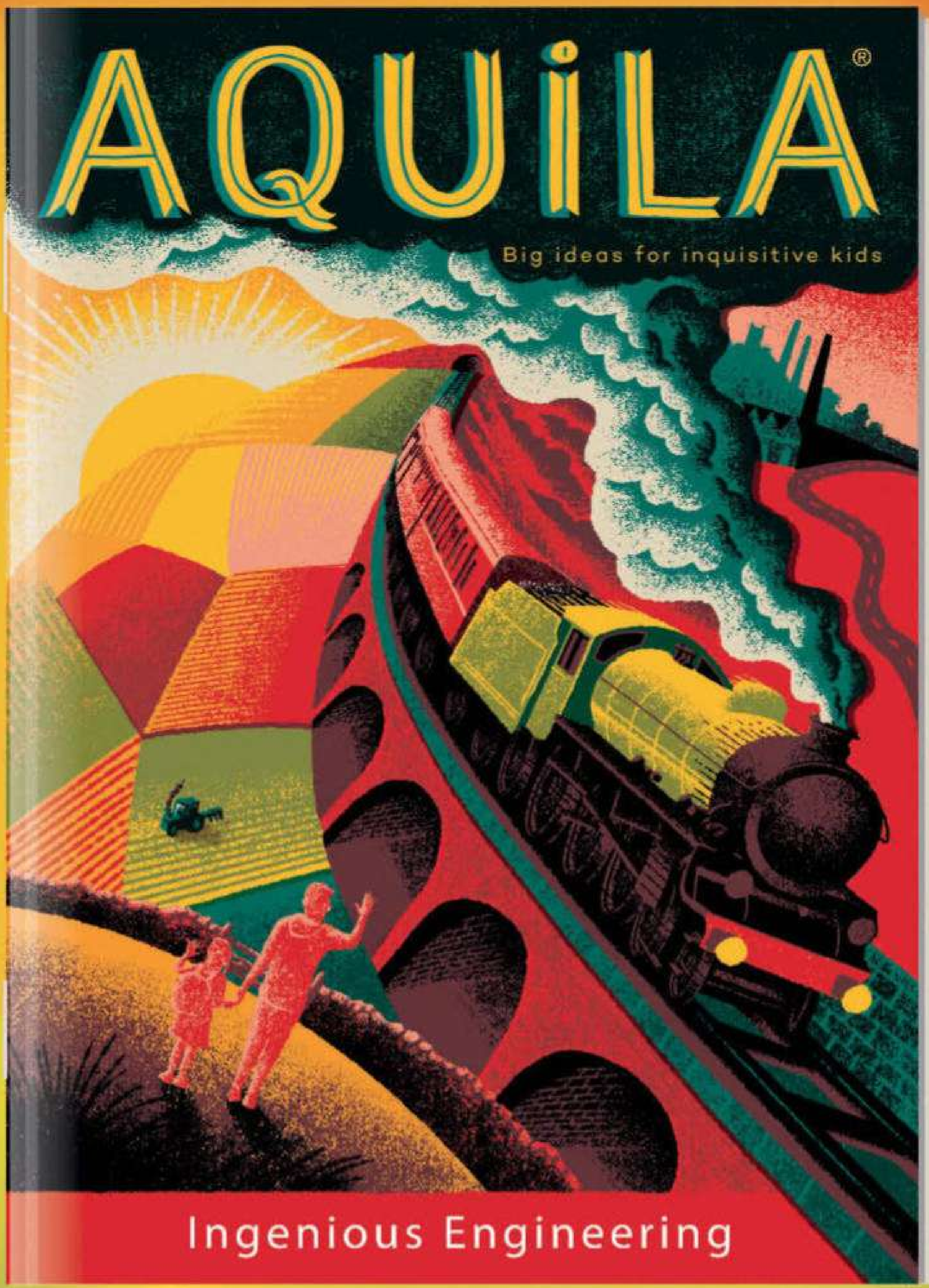

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Braintenance: How to create healthy habits and achieve your goals

In the first talk of our 2023 Big Thinkers Series, which is free for subscribers, neuroscientist Julia Ravey will discuss strategies we can employ to direct our focus, beat procrastination and stay motivated. On 22 February at 6pm GMT/1pm EST. Follow the link to register your place.

newscientist.com/braintenance

Tour

Morocco and the science of how to get more from your time

Join author and experience designer James Wallman on an immersive tour of Morocco that is informed by the latest discoveries from the science of experience. Mixing luxury and challenge, you will explore the sights, sounds, smells and tastes of Marrakesh and the nearby Atlas mountains. The 6-day tour begins on 24 May and costs £1579.

newscientist.com/tours

Podcast

Weekly

The podcast team discusses news that an ongoing bird flu epidemic has crossed into mammals. There is also evidence that our brains produce less entropy when we are asleep than when we are awake. In a bonus episode, podcast editor Rowan Hooper talks to Stuart Fowkes, founder of the Cities and Memory project, about sounds from the Arctic and Antarctic.

newscientist.com/nspod

PIDJOE/GETTY IMAGES

Taste of Morocco Let the science of experience be your guide

SLOWMOTIONGLI/SHUTTERSTOCK

Virus concern Bird flu has crossed to mammals including sea lions

Video

Instagram curator

Does the AI behind Instagram curate art in a similar or different way to a human curator? Laura Herman at the Oxford Internet Institute has been exploring the question and discusses her findings on our YouTube channel. They include the idea that the AI algorithm – unlike a human curator – selects images primarily on how recognisable they are.

youtube.com/newscientist

Newsletter

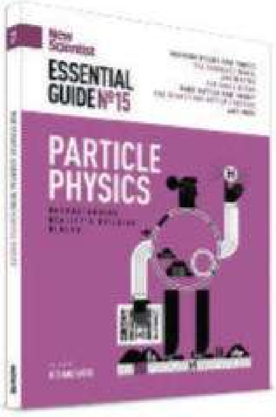
Lost in Space-Time

When we learned that the sun is mostly hydrogen, it took a battle against prevailing scientific wisdom before the discovery was accepted, writes Avi Loeb at Harvard University. Is scientific wisdom wrong again on the identity of interstellar objects, and might some be alien craft? We may soon test the idea.

newscientist.com/lost-in-space-time

Newsletter

"Laying the head of wishful thinking under the guillotine of data is difficult"



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It's time to save our rivers

Why we are shining a light on the UK's waterways crisis

ROY WALLER/ALAMY

RIVERS are the lifeblood of human civilisation. Our conurbations are built on them and have been since the very first cities (probably) were built along the courses of the Tigris and the Euphrates in what was then Mesopotamia. They remain necessary: life depends just as much on water now as it did then.

But in the crowded, urbanised world we live in, they are also increasingly valued for their beauty and restorative power, attracting walkers, kayakers and wild swimmers. It is understood that there are few things more uplifting to the human heart than a beautiful river, whether it is meandering through meadows or tumbling silver down rocks, and that such uplift has a considerable impact on our mental and physical health. The UK is one of a handful of countries in the world to quantify the beneficial impact of being around freshwater: it saves the nation's health services £870 million a year.

So we need our rivers and we love them too – yet we neglect them. We obstruct them, making it impossible for wildlife such as eels to travel upstream. We turn them into concrete canals, where little can grow. We allow rubbish to mount up on river beaches and catch on every fallen branch, poisoning and sometimes literally strangling the creatures that live in the water. We dump raw sewage into rivers, over and over again. Pesticides and farm waste leach in off the land. Less visibly, old mines seep poison into them.

In some places, so much water is extracted from the rivers themselves, or from the underground water caches they spring from, that they are quite simply disappearing. Recently, we reported on what has happened to "the Nile of America", the glorious Colorado river, which no longer reaches the sea.

In 2016, the International Union for Conservation of Nature published a report on the state of the UK and the Republic of Ireland's rivers. It concluded that "truly natural environments that have escaped both direct and indirect human alteration no longer exist". Things haven't improved since. No rivers in England, Wales or Northern Ireland are considered to be in high ecological health, and only 14 per cent of England's rivers qualify as good. When you take chemical pollution into account, no rivers in these three nations are deemed as being good. Not one.

> **"No rivers in England, Wales or Northern Ireland are deemed to be in good health. Not one"**

The UK has legislation in place to protect its rivers, yet it appears to make little difference.

Why does this matter more than the similar befouling and despoiling of some patch of land nearby? Why focus on rivers?

Rivers and other wetlands make up a very small fraction of Earth's surface, but, according to the

SAVE BRITAIN'S RIVERS

United Nations, they are home to 40 per cent of all plant and animal species. In the UK, a tenth of biodiversity depends on them. Their significance to our biosphere is tremendous. So how we treat our watercourses has vast implications for our future, far beyond the poisoning of swimmers forced to pass through sewage, or unsightly "wet wipe beaches" (see "Why our rivers matter", page 12).

New Scientist hasn't committed to a campaign in many decades, but over the course of the next year, we will be fighting to save the UK's rivers. We are a global magazine, but for a campaign to make sense, it must have achievable targets, so we have decided to start with the UK, a relatively small and rich group of islands where there is no excuse at all for how filthy its rivers are. Yet we will be mindful at every step to make sure the stories we publish – whether they cover the science of why rivers matter or how to find out if your local stream or river is healthy – will be of interest to a global audience.

We are embarking on this campaign, named Save Britain's Rivers, with our sister publication, the *i*. Edited by Oliver Duff, it is a newspaper with impressive reach in the UK and a shared passion for environmental causes.

Over the next year, in tandem with the *i*, we will be doing deep dives into the science of what is happening to UK rivers, as well as a host of hard-hitting news stories, films, podcasts and events on the subject. We will also be celebrating the glory of our rivers, in England, Wales, Scotland and Northern Ireland, and asking readers to tell the story of their local watercourse. More on that later. We will also seek out rivers around the world that are exceptionally well cared for, and investigate why and how.

So what do we hope to achieve over the next year? Three things.

First, we want to find out what is really happening to the UK's rivers and why.

Second, we want to build on the superb work that so many scientists and activists, such as Feargal Sharkey, have already done in bringing the plight of the UK's rivers to public notice. We want more people to understand what is going on.

Third, we want to draw up a pragmatic, apolitical manifesto for rivers, a blueprint for how they can be much better looked after. We hope this manifesto could be picked up and adopted by any political party interested in saving our rivers.

The UK can look after its rivers better. Much better. So let's, together, make it happen. ■

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KLEBHER VASQUEZ/ANADOLU AGENCY VIA GETTY IMAGES

A dead pelican, possibly infected with bird flu, in Lima, Peru, in December

Viruses

Bird flu's pandemic risk

Amid the global outbreak in wild birds and poultry, the virus could evolve to spread among people. Are we prepared, asks **Clare Wilson**

A HORDE of influenza viruses is sweeping through wild bird populations around the world. If any gain the ability to spread between humans, we may face a deadly flu pandemic.

Last week, World Health Organization (WHO) head Tedros Adhanom Ghebreyesus said that while the risk to humans is low, "we cannot assume that will remain the case and we must prepare for any change in the status quo". So, how ready are we for such a pandemic?

Flu viruses constantly mutate. Periodically, they can cross over from animals to people, or hybrid animal-human strains emerge, and these can be more dangerous.

Since 1997, there have been multiple deadly outbreaks in poultry farms of a subtype of the bird flu virus called H5N1, which doesn't readily infect humans.

In birds, H5N1 has diverged into more than 30 genetic variants, which have caused a large number of deaths in wild bird populations and killed some mammals that feed on birds, although there is as yet no evidence the variants are being passed between mammals.

Animal health experts are tracking flu cases, including bird flu, among animals around the world. Ian Brown at the UK's Animal and Plant Health Agency says parts of South America may need help with this. The region has seen several large outbreaks in wild birds and may be under-resourced for tracking, he says.

If bird flu does evolve to spread between people, vaccines based on that specific strain would be needed. Many new types of flu vaccine are in development, including ones made from mRNA, the basis for some of the vaccines for covid-19, which is caused by a coronavirus. Nevertheless, the tried and tested flu vaccines already have a huge industry behind them and would be the mainstay of the vaccine response, says Wenqing Zhang at the WHO.

> "Lessons learned and experience gained from covid-19 are valuable for future pandemics"

Manufacturers such as GlaxoSmithKline and Sanofi already change the flu strains in their seasonal vaccines each year, depending on what has recently been circulating. It takes only about four months from selecting the strains to producing a vaccine.

The WHO has sent samples of some H5N1 viruses to vaccine manufacturers, but mass production can't begin because we don't know which of its genetic variants may cause a pandemic, says Zhang. It might not even be one of the 30 variants that are circulating, but one with further changes that hasn't yet emerged. "For a vaccine to be effective, you need to make sure that the viruses contained in the vaccines match well those viruses causing infections," says Zhang.

Unlike at the start of the covid-19 pandemic, some antiviral drugs are available that can be given to people with severe flu, such as oseltamivir. The WHO is in talks with manufacturers about donating such medicines to low and middle-income countries if a bird flu pandemic were to start. But we must "cross our fingers" that any pandemic bird flu virus would be susceptible to these antivirals, as new pathogens can evolve resistance, says Zhang.

Lateral flow tests, also known as rapid antigen tests, proved useful during coronavirus surges to let people know if they should isolate. These are available for flu viruses that infect people and could be scaled up for bird flu.

Overall, Zhang says that if a bird flu pandemic begins, the world would be more prepared than it was before covid-19. "Lessons learned and experience gained from covid-19 are valuable for preparing for future pandemics," she says. ▮

Ecology

Doubts over the wood wide web

Claims that trees communicate via an underground network have been widely propagated, but a review suggests they aren't based on solid science, reports **Luke Taylor**

THE idea that trees communicate and share resources via an underground network of fungi, sometimes called the "wood wide web", has little supporting evidence, say researchers who have reviewed the science.

Mycorrhizal fungi live on plants' roots. They are thought to be beneficial to trees and to grow into vast networks beneath the forest floor. In recent years, books and documentaries have popularised the idea that these networks help trees recognise related individuals, allowing them to shuttle resources to feed their own seedlings, and even send alarm calls to their kin when under threat.

Justine Karst at the University of Alberta in Canada and her colleagues reviewed 1676 studies on the structure and function of mycorrhizal networks and were surprised to find that three major claims about fungi's partnership with trees are based on only a few studies that have been cited repeatedly (*Nature*, doi.org/jwrz).

Firstly, the authors say more studies are needed to establish whether mycorrhizal networks really are widespread in forests.

Researchers have mapped mycorrhizal networks by analysing fungal and plant DNA at trees' roots, but this has only been conducted on two of the world's 73,300 tree species.

"There's some evidence and we do think it's possible that these trees are connected, but as for the structure of the mycorrhizal networks, we don't have a good handle on that," says Karst. It is also unclear how long those networks last, she adds.

Secondly, the researchers looked at studies testing whether the trees could help their seedlings by sending them nutrients. The most-cited studies compare two sets of tree seedlings: one planted inside mesh bags and one freely in the soil. The mesh lets water and nutrients in and out, but blocks fungi, preventing mycorrhizal networks from forming.

MARIEKE PECHE/SHUTTERSTOCK

It is unclear whether the trees in a forest really are all connected

"To build a narrative that trees are recognising their kin or sharing resources is unfounded"

Mycorrhizal fungi are mostly made up of branching threads called hyphae

EMMANUEL LATTES/ALAMY

Those studies show that tree seedlings without the mesh fare better, suggesting that they prosper as mycorrhizal networks connect trees to one another.

But, by restricting the fungus, the tests may do more than just stop fungi communicating. The mesh could also restrict the amount of soil the fungus connected to the seedling can tap into, impairing other functions beneficial to the seedling, such as taking up water and nutrients.

Out of 28 field studies using mesh, only five found that seedlings did better in survival or growth when connected through a mycorrhizal network and just as many studies found negative effects, the review found.

Thirdly, the team also found little evidence that the trees could recognise their kin or send alarm calls when threatened.

The only peer-reviewed study suggesting trees can communicate with one another via a mycorrhizal network was done in a greenhouse. Levels of carbon passing through the fungus and the activity of defence enzymes in recipient plants increased when the trees were eaten by insects, suggesting they were sending warning signals, but that effect ceased when the trees' roots could intermingle as they would in a forest.

"The evidence is just so scant, and even in some cases contrary, so to build a narrative that trees are [recognising kin or sharing resources] is unfounded," says Jason Hoeksema at the University of Mississippi, a co-author of the review.

Amazing interactions

Karst and her colleagues call for more research to understand the structure and activity of mycorrhizal networks.

Hoeksema says what is clear is that fungi play a significant role in the life of trees, passing them nitrogen, phosphorus and other nutrients from the soil, while the trees give the fungi sugars. "There's actually plenty of strong evidence for all kinds of cool, amazing aspects of forest-fungal interactions that we could equally tell great stories about that are based on solid science," he says.

Suzanne Simard at the University of British Columbia in Canada, who has written books on how trees communicate via fungi, says she stands by her research.

"Reducing ecosystems to their individual parts hinders us from understanding and appreciating the emergent relationships and behaviours that make these complex ecological systems thrive," she says. "It is my hope that, in time, forest scientists will come to understand ecosystems as complex systems." ■

Society

Couples are most in love in Hungary, according to science

Alice Klein

PEOPLE in relationships report being more in love if they live in a country with high living standards, greater gender equality and a community-centred culture.

To find out how experiences of love differ, Piotr Sorokowski at the University of Wrocław, Poland, and his colleagues surveyed 9474 adults in any form of romantic relationship across six continents.

The participants were given 45 statements, such as "just seeing my partner excites me", and were asked how strongly they agreed with each on a scale from 1 to 9.

Hungary's respondents had the highest "love scores" on average, followed by Malaysia, Portugal, the US and Italy (*Scientific Reports*, doi.org/grnn3k). The lowest scores were recorded in Austria, Jordan, South Korea, Uganda and Pakistan. The UK wasn't included.

In general, the participants from countries that sit higher on the United Nations' Human Development Index had greater love scores. Good living conditions may make it easier to be engaged with your partner, says Sorokowski.

Those from countries with greater gender equality also had higher love scores. This may be because women in these countries have more agency to choose partners they like, says Sorokowski.

Lastly, participants from more collectivist cultures, which stress the good of the community over the self, tended to have higher scores than those from individualistic countries. People from collectivist countries may be more selfless towards partners, which could lead to stronger bonds, says Sorokowski.

"Conducting cross-cultural research on love allows us to gain a deeper understanding of this complex and universal emotion and promote empathy and understanding between cultures," he says. ▮

Neuroscience

Your brain produces more entropy while you are awake

Karmela Padavic-Callaghan

OUR brains produce more entropy when we are awake than when we are asleep. The finding could lead to better ways to measure the consciousness of people who appear to be in a coma.

Entropy is a measure of disorder, and in our universe, everything tends to move from less disorder to more over time. For instance, breaking a coffee cup increases entropy. While this breaking can happen in many ways, you never see a broken cup spontaneously re-assemble itself and therefore decrease its entropy.

Electrical signals in our brains can also produce entropy as part of processing and transmitting information, such as the visual signals from our eyes. Rodrigo Cofré at the Paris-Saclay University in France and his colleagues wanted to determine whether our brains produce more entropy when we are awake or when we are asleep.

Our brains produce entropy as they process information

The researchers used functional magnetic resonance imaging (fMRI) to scan the brains of 15 people in different states of consciousness: while each person was awake and in three stages of sleep, from light to very deep.

To calculate entropy, the team used a model that was previously developed from studying the pathways that electrical signals can follow inside of the brain. The different routes help reveal the different processes they can carry out, and each of those processes produces different amounts of entropy. From this, the researchers calculated entropy production for each person in each state of consciousness. The researchers found that entropy decreased as people fell deeper into sleep. In the state of deepest sleep, people's brains, on average, produced 25 per cent less entropy than when they were awake (arXiv, doi.org/jwbh).

25%

How much less entropy our brains produce while asleep

Cofré says that this gives researchers a way to quantify consciousness – a person whose brain shows the same amount of entropy production in an fMRI study as someone who is deeply asleep is likely to have the same types of processes happening in their brain and to be at a similar level of consciousness, he says.

The new method could then potentially be used to quantify the consciousness of people in comas or eventually help to diagnose people with locked-in syndrome, who are conscious but unable to communicate with the external world, says Cofré.

Previous research has linked consciousness to entropy. Some fMRI studies, for example, have indicated that states of very altered consciousness, such as those induced by psychedelic substances like psilocybin, result in an increase in entropy of the brain itself – meaning that it is harder to predict its overall electrical state – and not just the entropy different signals produce.

Dan Lloyd at Trinity College in Connecticut says that understanding the state of awareness of people that are minimally conscious has long been an area of study. However, it isn't yet clear that entropy production is an unambiguous mark of consciousness.

For example, dreams can happen in deep sleep – a time of low entropy – but they reflect "a high level of consciousness", says Lloyd. As such, dreams could actually increase entropy production in the brain, but the study didn't consider this, he says. ▮

SHUTTERSTOCK/GORODENKOFF

Environment

Why our rivers matter

SAVE BRITAIN'S RIVERS

There are 200,000 kilometres of wildly varying waterways in the UK, but do we understand their true value and the threats they face, asks **Graham Lawton**

HENRY CIECHANOWICZ/ALAMY

The river Dee flows through England and Wales

STAND by a river in the UK and you are in touch with the ancients. Their short, gruff names – Thames, Leith, Taff, Lagan – speak volumes of the history of the islands, from ancient Britons through Romans, Saxons and Vikings. These rivers are part of the past and present. Yet they face an uncertain future.

All over the world, rivers are valuable, often sacred, cultural and practical assets. They are a defining feature of human settlements, exploited for millennia as a source of drinking water, food, irrigation, waste disposal, power, navigation, defence and even inspiration.

In the UK, many of these services are just as relevant today. Tap water comes mostly from rivers. Sewage is disposed into them – preferably treated but often not. Rivers irrigate crops, power homes, take away floodwaters and float boats. Millions of people spend some of their leisure time messing about on, or near, rivers.

The UK is a riverine country. Globally, about 0.8 per cent of the land is covered in freshwater. In the UK, that number is 3 per cent. It has about 1500 river systems, with a combined length of over 200,000 kilometres, ranging from gushing upland headwaters to languid floodplain meanderers, via a vast range of intermediate habitats.

By global standards, these rivers are short, narrow and shallow – “mere streams”, according to the National River Flow Archive at the UK Centre for Ecology & Hydrology in Wallingford. Yet they are extremely diverse in character. According to a recent report by the National Committee UK of the International Union for Conservation of Nature (IUCN), “rivers and their floodplains are among the most important environments in the UK”.

“It’s well known that rivers and their floodplains – and the two go hand in hand – support a disproportionate level of biodiversity relative to their size within landscapes,” says report co-author Stephen Addy at the James Hutton Institute in Aberdeen, UK.

Although rivers are important for many reasons, their most obvious benefit in the UK is the water they supply. According to Water UK, which represents the country’s water industry, about two-thirds of tap water in England and Wales comes from rivers and the reservoirs and lakes they flow into; the rest is taken from aquifers. Northern Ireland and Scotland rely almost exclusively on rivers, reservoirs and lakes. All told, 87 per cent of the UK water supply comes from these sources.

9.6km^3

Volume of surface water extracted in the UK for use each year

10%

of UK freshwater and wetland species are at risk of extinction

210

Number of chalk streams in the world - most of them in England

According to government statistics, water companies in the UK abstract about 4.6 cubic kilometres of river, lake and reservoir water in England for the public supply every year. People drink it, bathe in it, flush their toilets with it, irrigate their gardens with it and use it to wash their clothes, floors and cars. Offices, shops, restaurants and other firms drink deep of it too.

Water is abstracted for other purposes. Electricity generators take 3.4 cubic kilometres to turn their steam turbines, while fish and watercress farms use 0.8 cubic kilometres and agriculture and private water supplies another 0.8. That adds up to a grand total of 9.6 cubic kilometres, equivalent to a cubic tank of water more than 2 kilometres in all dimensions.

Even in a relatively rainy country like the UK, that is milking it. The UK government estimates that about 1 in 5 surface water sources are depleted by over-abstraction, which has knock-on effects on river health.

The opposite problem – too much water – is an increasingly familiar hazard during the winter. Flooding is a growing problem as climate change causes extreme weather events, including biblical downpours. According to the Environment Agency, the UK has had six of its 10 wettest years on record since 1998. Last year was the first to see three named Atlantic storms in the space of a week.

Natural floodplains can help to mitigate flood risk by corralling the excess water and releasing it slowly back into the river. That is especially true of riverine landscapes engineered by beavers, whose dams and pools massively slow the passage of water through the system. Where rain used to hit the ground and surge straight into the waterways, it now is trapped for weeks. Beavers are being reintroduced all over the UK after they gained legal protection last year.

Natural services

The problem is that many of those floodplains are far from natural, let alone beavered: housing estates and industrial development are often sited on them and these are generally quite useless at mitigating floods.

Water supplies and flood defences are two of many "ecosystem services" supplied by rivers. These are vital goods and services, such as water, pollination and clean air, that flow from nature, or what is increasingly referred to as natural capital.

The UK was the first nation – and remains one of only 26 countries – to audit its natural capital. In 2012, the government established the (now disbanded) Natural Capital Committee (NCC) to advise it on the state of England's natural capital, in order to help deliver its commitment "to be the first generation to leave the natural environment of England in a better state than it inherited". In 2020, the NCC published its first set of accounts.

These are by no means complete, as the system for totting up natural capital, called experimental ecosystem accounting, remains a work in progress and nature is complex. But they still speak volumes about the value of rivers.

Water abstraction alone is worth £6.8 billion a year – essentially what it would cost to keep the taps on if rivers didn't supply the UK with water – and the asset is worth £134 billion (the NCC stressed that these aren't price tags on nature: given that the natural world supports all life on Earth, its value is infinite). Wetlands sequester 3.5 million tonnes of carbon a year, worth £831 million; that asset is valued at nearly £30 billion. Hydroelectricity generation produces 6865 gigawatt-hours a year, worth £136 million; the value of that asset is £2.2 billion.

These "provisioning and regulating" services are supplemented by some less tangible, but no less valuable cultural services. Around 1 in 10 of the UK's 5.8 billion annual outdoor recreational and tourist visits are centred on freshwater, worth £681 million; the asset is worth £32 billion. Recreational fishing is a £1.7 billion a year industry. Around 2.7 million people gain health benefits from being in or around freshwater, worth £870 million a year. The asset value of this is nearly £48 billion. Even house prices benefit from the proximity of a river to the tune of £2.9 billion a year.

Plastic waste dumped along the bank of the river Thames in London

MARK PHILLIPS/ALAMY

One asset that has yet to be incorporated into natural capital accounting is biodiversity, but it is clear that rivers are an important repository of what is left in the UK.

"Rivers and their floodplains support a disproportionate level of biodiversity relative to their size"

Globally, rivers and other bodies of fresh water are disproportionately biodiverse. Despite covering less than 1 per cent of Earth's surface, they are home to around a third of described species of vertebrate, including approximately 40 per cent of all fish.

The UK's rivers and the wetlands they feed are disproportionately biodiverse too, though to a lesser extent. They are home to around 10 per cent of the UK's species, according to the Environment Agency. The IUCN lists 346 river-dependent species, some endangered, including eels, otters, the bar-tailed godwit and feather mosses. The Environment Agency says that over 10 per cent of UK freshwater and wetland species are threatened with extinction.

Rivers are biodiverse in part because they themselves are diverse. A short stretch of lowland river can feature 10 different habitats – pools, riffles (shallow water flowing quickly over stones), glides (deeper, slow-flowing water), backwaters, beds of aquatic vegetation, submerged tree roots, exposed sediment, riverbanks, riparian vegetation and floodplains – all of which provide food and shelter for a different repertoire of species. Further upstream are headwaters, waterfalls and rapids, which also host specialist species such as the freshwater pearl mussel, white-clawed crayfish, brook lamprey and bullhead, as well as juvenile salmon, trout and grey mullet. These juvenile fish will eventually migrate out to sea and become part of the UK fishing industry's £713 million annual earnings.

England is also home to the vast majority of the world's chalk streams, rare and internationally important habitats fed from alkaline aquifers in chalk and characterised by their gravel and flint beds and crystal clear water. They are home to unique ecosystems and have been described as an English Great Barrier Reef. There are only 210 of these waterways in the world and 170 of them are in England (the rest are in northern France).

Unsurprisingly, the value of ecosystem services is strongly related to the ecological state of the asset. In much of the UK, that isn't a happy tale. England, Wales and Northern Ireland have no rivers considered to be in high ecological health, according to criteria laid down in the four nations' Water Framework Directives; only 14 per cent are good. The rest are moderate, poor or bad. None is in a good state in terms of chemical pollution and none is in good overall health. In Scotland, 8 per cent of rivers are in high ecological health.

The IUCN report is blunt on this issue, concluding that "truly natural [river] environments that have escaped both direct and indirect human alteration no longer exist". However, there is hope, according to Addy. "There are some grounds for being optimistic. River restoration in the UK is undergoing a step change, there are more and more projects going on everywhere." ■

Human evolution

Curly hair protects us from the sun

Tightly coiled hair stops heads overheating more effectively than straight or moderately coiled hair, which may explain why it evolved in the first humans, writes **Michael Le Page**

HAIR that is tightly coiled offers the best protection against the sun's potentially damaging rays, which could explain why this trait evolved in early humans in Africa and straighter hair emerged as some humans moved into cooler areas.

It has long been suggested that the reason our body hair became so fine that it is sometimes barely visible, while our scalp hair remained thick, is to prevent our heads from overheating in the sun. In our bipedal ancestors, the beneficial shading effect of head hair may have outweighed its insulating effect.

Tina Lasisi at Penn State University wondered if the type of hair on a person's head also makes a difference.

To learn more, Lasisi and her colleagues put three different wigs on a thermal manikin – a model of the human body with heaters and sensors that is used to measure the thermal effects of clothes.

All the wigs were made of human hair from people of Chinese descent. One wig was straight, one had moderate curls and one had tight curls. Lasisi says the tightly coiled wig was within the range of curl found in people of recent African ancestry.

In tests in a climate-controlled wind tunnel, the team found that the hair's type made a big difference to how much heat the head of the manikin gained from simulated sunshine at 30°C (86°F).

The head with a straight wig gained less than half as much heat as a control head with no wig. The head wearing the moderately curled wig gained around a quarter as much heat and the head with the tightly curled wig gained less than a tenth as much as the no-wig control (bioRxiv, doi.org/jwjn).

The researchers think that curls reduce how much heat reaches the skin by increasing the gap between it and the hair surface. Making straight hair longer doesn't achieve this because it flops over and lies flat, says Lasisi.

What's more, curlier hair appears to maximise the shielding effect from the sun while minimising an unwanted insulating effect. "It has this incredible way of bypassing this trade-off," says Lasisi.

"Biologists study skin colour evolution, but this is the first study to look at the evolution of hair type"

The results also show that all the tested hair types reduce the cooling effect of sweating. When wetting the manikins to simulate sweat, the head with no wig lost twice as much heat via evaporation as those with the wigs.

However, having any head hair more than halves the amount of sweat that is required to prevent the head from gaining heat, with tightly coiled hair reducing this more than moderately curled or straight hair, the results show. Hair, particularly if tightly coiled, therefore lowers the amount of sweat that is required on the scalp to balance the sun's heat.

"Any mechanism that could help cool the body, and at the same time save precious water, would definitely have been acted on strongly by natural selection," says Joseph Graves at North Carolina Agricultural & Technical State University.

When some humans left Africa and moved into cooler climes, the selective pressure for tightly coiled hair would have been lost, says Lasisi, allowing variations to emerge from generation to generation by random chance, but the trait may have re-evolved in some peoples.

JACK JEFFRIES/CAVAN IMAGES/GETTY IMAGES

Curly hair shields people from the sun without excessive insulation

The study's findings are important because they could help change some people's prejudiced views, says Graves, who is the co-author of *Racism, Not Race*. Research into the physical traits of the first humans can help to erode racist ideas, he says.

First of its kind

The first humans would have had black skin and tightly curled hair, says Graves. It was only relatively recently that other skin colours and hair types appeared, he says. Biologists have begun to study the evolution of skin colour, but this is the first study to look at hair type in an evolutionary context.

"This is indeed a first-of-its-kind study," says Gill Westgate at the University of Bradford, UK. "It is fascinating that curly hair protected against incident solar thermal effects, which would have been important in the development of bipedal hominins."

According to Lasisi, many aspects of the manikins used in the study don't match human physiology. Much more work needs to be done to understand the effects of hair type and how significant a factor it was during our evolution, she says.

Hair type has previously been studied by researchers in fields such as cosmetics and forensics, but not from an evolutionary perspective, which is probably a reflection of that field's history, says Lasisi.

"When it comes to anthropology, it has this history that's tightly woven with colonialism and racism," she says. "What kind of Victorian gentleman would have thought that a trait he did not possess could be critical to human evolution?"

Solar system

Distant, tiny world Quaoar has a ring that seems to defy laws of physics

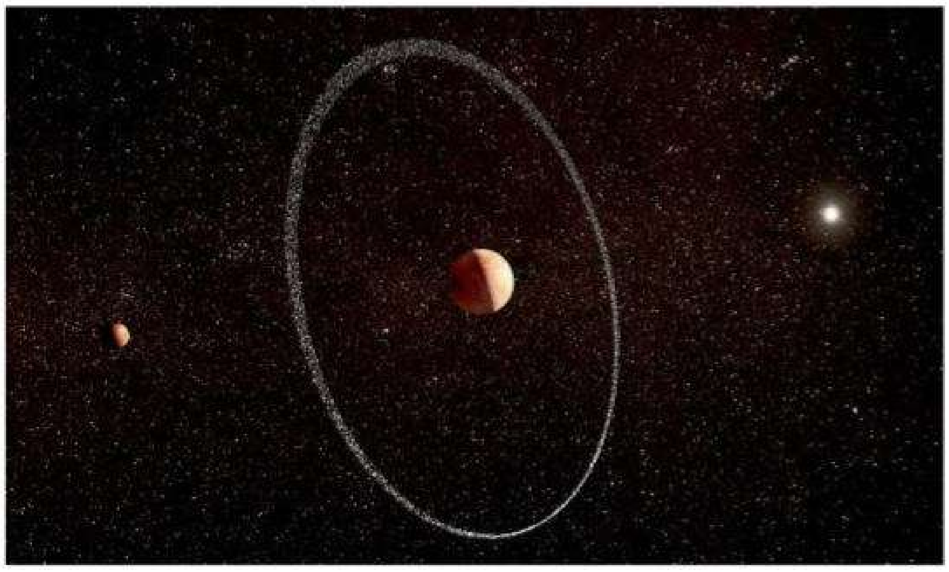
Alex Wilkins

QUAOAR, a dwarf planet that sits beyond Neptune in our solar system, appears to have a ring of debris around it that is way further out than was thought possible.

"We have observed a ring that shouldn't be there," says Bruno Morgado at the Federal University of Rio de Janeiro in Brazil.

Until now, every ring or orbiting moon observed has obeyed a limit put forward by the astronomer Édouard Roche in 1848 that relates to its distance from a parent body. If an object is below the Roche limit, its parent body's gravity rips apart the orbiting object into a collection of smaller chunks that eventually form a ring, like those seen around Saturn. Outside that limit, dust and debris should coalesce to form larger objects, such as moons.

Quaoar, which is 1110 kilometres across and slightly less dense than our moon, should have only moons beyond a distance of 2.4 times its radius, but Morgado and his colleagues measured the ring at 7.2 times Quaoar's radius. "It's very, very far outside this limit," says Morgado.



ESA

Artist's illustration of a ring of debris encircling dwarf planet Quaoar

To spot Quaoar's wayward ring, the team observed the dwarf planet against the backdrop of various stars between 2018 and 2021, using Earth-based telescopes as well as the European Space Agency's CHEOPS exoplanet-hunting space telescope. The researchers were able to use changes in the stars' brightness to calculate the ring's characteristics.

They found that it appears to be mostly made up of water ice, a bit like Saturn's F-ring. One unusual feature is its irregular shape – some sections of the ring are 5 kilometres wide, while others span more than 100 kilometres (*Nature*, doi.org/jv93). If you stood on Quaoar's surface, you should be able to see some of the ring's wider sections, says Morgado.

It isn't clear why Quaoar has a ring so far outside its Roche limit, but researchers think the low temperatures – the dwarf planet is a frosty -220°C – might prevent the ring's contents from coalescing.

It is also possible that interactions between the ring's particles or with Quaoar's moon, Weywot, could be sustaining it. Further observations of Quaoar and more simulations of the system will be needed to find out, says Morgado.

Whatever the answer, we might need to modify the Roche limit, which could have implications for other calculations in astrophysics.

"This concept has been used to analyse, for instance, the formation of our moon," says Morgado. "So, if we have seen something that challenges this limit, we need to rethink and better understand why this ring is where it is."

Carl Murray at Queen Mary University of London is hopeful this won't change things too much, because the Roche limit is only a rough guide.

"The Roche limit has its uses, but, in reality, there's no exact radius," says Murray. "It'll depend on the physical properties of the material that's orbiting and, as they've shown here, there are other characteristics that need to be taken account of as well." ▮

Diseases

Massive tick-killing effort fails to reduce Lyme disease cases

KILLING ticks reduces the number and proportion that carry the main bacterium that causes Lyme disease (*Borrelia burgdorferi*), but doesn't lead to fewer reports of people getting sick, according to the largest study of its kind.

Rates of Lyme disease in the US have increased in the past four decades to at least 30,000 cases reported each year. The rise has spurred research, including on a Lyme disease vaccine close to completing clinical trials, as well as on ways to prevent infection from the ticks that transmit the disease.

Black-legged or deer ticks (*Ixodes scapularis*) can transmit *B. burgdorferi* to humans through bites. The ticks become infected when they feed on the blood of infected animals, such as mice or small birds.

Over four years, Richard Ostfeld at the Cary Institute of Ecosystem Studies in New York and his colleagues tested two different tick control methods both separately and together across 24 neighbourhoods in Dutchess county, New York, with more than 2000 people and 849 pets participating in the trial. They tested an anti-tick fungal spray called Met52, spraying all vegetation on properties and several metres inside surrounding forested areas, as well as boxes that brush small mammals with an anti-tick chemical.

Although the researchers found that both methods reduced the abundance of ticks, and the spray lowered the proportion of ticks infected with the Lyme bacterium, there was no effect on the rate of Lyme disease or other tick-borne disease reported in people, compared with placebo controls. Rates of tick-borne disease reported in pets were lower by around half, however (*Pathogens*, doi.org/jwbg).

> **"Rates of Lyme disease in the US have increased to at least 30,000 cases reported each year"**

The findings add to evidence that such tick-control methods, at least as currently used, don't reliably protect people from disease, says Neeta Connally at Western Connecticut State University. ▮

James Dinneen

Archaeology

Twist in tale of ancient tool use

A trove of artefacts from Kenya shows that relatively sophisticated stone tools were crafted by even our very early relatives, reports **Michael Marshall**

A SET of stone tools found in Kenya is the oldest of its kind, and one of the oldest known to have been made by ancient hominins. The find adds to the evidence for widespread tool use relatively early in human evolution.

The artefacts were found with two teeth belonging to hominins called *Paranthropus*. They weren't thought to make tools because their teeth were well-suited to chewing food, but the new evidence suggests they actually did make and use stone tools.

The finds come from Nyayanga on the north-eastern shore of Lake Victoria in Kenya. Tom Plummer at Queens College, City University of New York first learned of them more than 20 years ago, while working at another archaeological dig nearby, but it took until 2015 to begin full excavations.

The team has since recovered 330 stone artefacts. They include the heavy cores of pebbles, used for pounding, and sharp cutting flakes that had been removed from them. The tools are a type known as Oldowan, named for Oldupai gorge in Tanzania where the first examples were found.

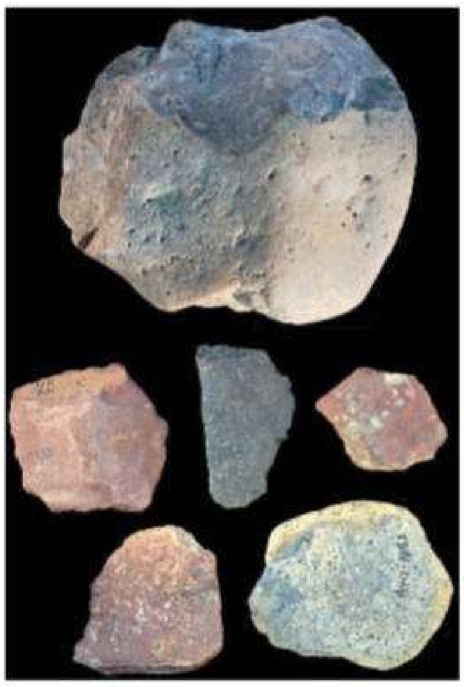
Based on analyses of the sediments in which the Nyayanga tools were found, and the types of fossils found with them, the team estimates they are between just over 3 million and 2.6 million years old. "We think it's in the older end of that range," says Plummer. This would make them the oldest Oldowan tools on record. Previously, the oldest known examples were those from Ledi-Geraru in Ethiopia, which are from 2.6 million years ago.

The Nyayanga tools were used to process a variety of foods, says Rahab Kinyanjui at the National Museums of Kenya. The team found bones of hippopotamus-like animals, some of which had cut marks on them, suggesting the tools were used for butchery. The heavier implements were also used to pound plant materials like tubers and fruit (*Science*, DOI: 10.1126/science.abo7452).

J.S. OLIVER, HOMA PENINSULA PALEOANTHROPOLOGY PROJECT

Archaeologists working at the dig site in Nyayanga, Kenya

Oldowan-type stone tools from Nyayanga, used for cutting and pounding tasks


HOMA PENINSULA PALEOANTHROPOLOGY PROJECT

Who made the tools?

Finding Oldowan tools in Kenya that date so far back, and the fact they were 1300 kilometres from Ledi-Geraru, suggests stone tool use was already widespread at this time, says Plummer.

The use of such implements is primarily associated with the *Homo* genus, which includes our own species *Homo sapiens*, as well as older ones like *Homo erectus*. The oldest purported *Homo* remains are 2.8 million years old, but none have been found at Nyayanga. The only hominin remains there so far are of *Paranthropus*.

Paranthropus lived alongside other hominins, including *Homo*, for over a million years. However, it is generally thought that they hit an evolutionary dead end. Compared with other hominins from the same time, they looked less like us: in particular, they had very large teeth, perhaps for grinding up tough plant foods.

"The thing about *Paranthropus* is they've got a really specialised anatomy," says Plummer. "They've got the biggest jaws and teeth of any primate that ever lived, for their weight." He says it is unlikely that a tool-using animal would need such powerful chewing apparatus. But since it is the only hominin found at Nyayanga so far, he says it is worth seriously considering that *Paranthropus* made and used the tools.

> **"Several modern primates sometimes make crude stone tools, so why not a *Paranthropus*?"**

Others are less hesitant. "People are very shy about saying that it was not *Homo* something, *Homo habilis* or whatever, making tools," says Margherita Mussi of the Italo-Spanish Archaeological Mission at Melka Kunture and Balchit, based in Rome. She points out that several modern primates sometimes make crude stone tools, including chimpanzees and various monkeys. "So why not a *Paranthropus*?"

If that is true, it would fit with other evidence that species of *Homo* weren't the only hominins that made stone tools. The oldest known stone tools of any kind, at 3.3 million years old, are from Lomekwi in Kenya. They are cruder than Oldowan versions and were made in a different way: by hitting rocks on the ground, rather than hitting a rock held in the hand.

Studies like these suggest tool use goes back further than we thought, says Plummer. "We're going to be pushing tool use further back in time," he says. ■

Analysis Calorie restriction

Does permanently cutting calories slow ageing?

A blood test suggests that restricting our calorie intake reduces the rate at which we age, but the jury is out on whether this strategy really works, writes **Clare Wilson**

GOING on a permanent calorie-controlled diet may sound rather unappealing, yet a new study suggests it might slow your rate of ageing. Although few randomised trials have investigated such a diet, the latest study follows this good medical research practice. But the tests it used to measure ageing rates didn't all produce promising results.

The trial looked at the anti-ageing potential of reducing calorie intake over the long term. In mice, this extends their lifespan by as much as 50 per cent.

But we don't yet know if it has the same effect in people, because we live so much longer than most other animals and it is notoriously hard to stick to a calorie-restriction diet.

In 2007, the US National Institutes of Health (NIH) began a trial in which 220 non-obese adults were randomly asked to try to reduce the calories in their existing diet by 25 per cent or to eat what they liked. They were monitored for two years.

Despite the calorie-restricted group being coached on what kind of food to eat, they only managed about a 12 per cent cut in calories.

Nevertheless, the dieters did see reductions to their weight, blood pressure and cholesterol. But this doesn't tell us if their ageing slowed. As their ages spanned from 21 to 50 at the start of the study, they were unlikely to die from age-related conditions over the two years, regardless of their calorie intake.

In the new study, Daniel Belsky at Columbia University in New York and his colleagues carried out several tests on blood samples taken from the participants during the NIH trial.

The benefits of restricting calories may go beyond weight loss

MASKOT/GETTY IMAGES

Belsky's team sought to find out if their "biological age" differed from their chronological age. For instance, a 50-year-old could have a biological age of 40 if they have been living healthily and are likely to live for 10 years longer than average.

Several firms have developed commercial tests to assess biological age. These measure multiple blood biochemicals, sometimes combining them with other health indicators, such as smoking history. According to two of these tests carried out by Belsky's team, the diet had no effect on the participants' biological age.

But there was a small difference recorded by a third test, one developed by Belsky's team based on patterns of chemical modifications to DNA. Several studies show that the patterns of these modifications change as we age. This test doesn't measure current biological age, but the rate at which it is rising.

Those in the calorie-restriction group showed a 2 to 3 per cent slower speed of ageing, as measured by this third test (*Nature Aging*, doi.org/jwbs). Modelling suggests that translates into a 10 to 15 per cent lower risk of death over 13 years.

Belsky told *New Scientist* that the difference in results between the three tests could be because the third one is more sensitive to the small effects of a calorie-restriction diet.

Ultimately, however, we won't know if any of the biological ageing tests really work until studies have gone on for many years and they show that people with an apparently lower biological age really do live for longer. That means it will also be a long time before we know if calorie restriction slows ageing. ▮

Animal behaviour

Bandicoots can be trained to flee predators faster

VULNERABLE Australian marsupials such as bandicoots and bettongs often fail to recognise danger when they encounter invasive predators – but, with training, they may learn to escape more quickly.

These native mammals aren't adapted to the presence of introduced predators like foxes or cats, so they may lack the instinct to flee. Natasha Tay at Murdoch University in Perth, Australia, and her colleagues wanted to see if it were possible to teach small marsupials to recognise a threat.

They captured 178 animals, including three species of bandicoots, which typically move on four legs, and four macropod species, such as bettongs, which hop on their back two legs.

They brought these animals in turn to a 10-metre, partially enclosed area that was open on one side, lit with infrared lights and covered by cameras. There, they slowly released them from the capture bag, then Tay thumped the ground behind the animal using a pole with bells attached to encourage them to escape.

The species had varied responses to fleeing. The macropods typically relied on speed, taking off in a straight line, whereas the bandicoots would make more use of sharp turns while escaping.

Critically, when the researchers recaptured the same individuals on the following night and repeated the experiment, they found they became better at escaping. The animals waited less time in the bag and took off straight down the runway immediately (*Animal Conservation*, doi.org/jwbw).

"Training native fauna to become better at facing novel threats seems simple, but it is effective"

While this is just an initial experiment, Tay says it provides some hope. "We could potentially train the animals to be more effective [at escaping introduced predators]," she says.

"Training native fauna to become better at facing novel threats seems simple, but it is effective," says Georgia Ward-Fear at Macquarie University in Sydney. ▮

Joshua Rapp Learn

Geoengineering

Blocking sunlight with moon dust may ease global warming

Carissa Wong

LAUNCHING a dust cloud from the moon to reduce the amount of sunlight reaching Earth could help cool the planet – although such a strategy would require a lot of research and the risks to agriculture, ecosystems and water quality are unclear.

Previous research looked into the idea of placing more than 100 million tonnes of dust between Earth and the sun to partially block light from reaching our planet as a way to combat climate change. The particles would absorb light energy or scatter light away from Earth.

To achieve this, the dust would need to sit 1.5 million kilometres from Earth at the first Lagrange point, or L1, where the gravitational pull of the sun and our planet cancel out.

But energy from sunlight and charged particles ejected from the sun, known as the solar wind, would gradually nudge the dust further away from L1, which would need correcting.

Now, after running thousands of computer simulations, Benjamin Bromley at the University of Utah and his colleagues have found that continuously launching a stream of lunar dust from the moon's north pole towards L1 at 2.8 kilometres per second may be a better approach.

Their work suggests that each dust particle would spend about five days blocking Earth-bound sunlight, before drifting off.

Considering factors like the gravitational pull of the sun and the planets and the effect of the solar wind, the simulations found that maintaining a dust shield with a mass of 1 million tonnes near L1 for a year could dim sunlight across Earth by 1.8 per cent, equivalent to completely blocking six days of sunlight (*PLoS Climate*, doi.org/grq9zn).

If the approach were sustained until other measures were introduced to remove carbon dioxide from Earth's atmosphere, this could offset the increase in the gas's concentration that has occurred since the industrial revolution, says Ben Kravitz at Indiana University, Bloomington.

1 million

tonnes of moon dust would constantly be blocking sunlight under a mooted plan

"If this method works, it would certainly be effective at reducing global temperature, but it's hard to say whether it would be worth it relative to the effort and resources used," says Kravitz.

The simulations didn't model the use of any machinery to launch the lunar dust, but one option would be a railgun, which propels things via electromagnetic energy, says Bromley. "This would be perfect because it could be fuelled by a few square kilometres of solar panels placed near the launch site," he says.

However, shading Earth will have unequal effects in different regions, says Kravitz. "Temperature, precipitation, winds and many other things will change [as a result of this strategy]," he says. "Those changes will, of course, translate into effects on agriculture, ecosystems and water quality."

Large-scale engineering studies would be needed to assess this, says Curtis Struck at Iowa State University, and other possible effects would also need to be examined. "Would there be enhanced micrometeorite falls to Earth and damage to Earth-orbiting satellites?" says Struck.

Regardless, such an approach shouldn't replace our efforts to decrease carbon emissions, says Bromley. "We have to keep reducing the greenhouse gases within our own atmosphere, no matter what. Our dust shield solution would simply buy us more time." ▮

PAOLA IAMUNNO/ISTOCKPHOTO/GETTY IMAGES

Dust from the moon could work as a solar shield for Earth

Health

Brain pathway could be key to treating opioid addiction

Grace Wade

A NEWLY discovered brain pathway in mice may contribute to opioid tolerance, suggesting a possible target to prevent addiction and overdose.

Opioids can be effective painkillers, but also highly addictive, as frequent use means larger doses are needed to achieve the same effect. This raises overdose risk.

Research in animals – and some case reports in humans – suggest that opioid tolerance develops more quickly when the drugs are taken in the same environment, a process called associative learning.

To identify the mechanism behind this phenomenon, Wei Xiong at the University of Science and Technology of China and his colleagues studied 24 mice given daily morphine injections for five days. Mice given morphine in a setting used only for that purpose developed greater tolerance than those that got injections in their home cages.

After euthanising the mice, the team bathed slices of the animals' brains in a solution that marks areas that were recently active, and viewed them under a microscope. Compared with controls, mice in the greater-tolerance group showed signs of increased activity in three regions: the ventral hippocampus, dorsomedial prefrontal cortex and basolateral amygdala. These areas are known to be involved in memory, self-awareness and pain regulation, respectively.

The researchers then homed in on the neurons connecting these regions in mice with built-up tolerance, using a technique known as chemogenetics to activate or deactivate the cells. After four days of morphine injections, mice with active connections had nearly four times the drug tolerance of mice without them. This suggests the pathway governs the development of opioid tolerance in response to contextual cues, says Xiong. ▮

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JULIA RAVEY

Health

Chronic fatigue linked to gut bacteria

People newly diagnosed with ME/CFS have distinctive changes in their gut microbiomes

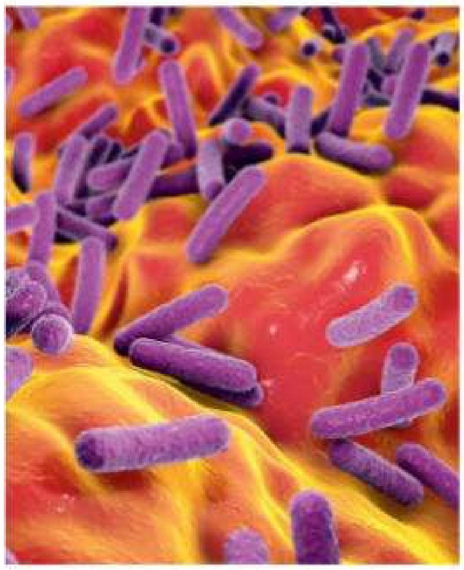
Grace Wade

PEOPLE recently diagnosed with chronic fatigue syndrome – also called myalgic encephalomyelitis or ME/CFS – have distinct differences in the gut microbiome compared with people who don't have the condition, suggesting that disruptions in gut bacteria may be related to its onset.

ME/CFS is a chronic illness affecting some 17 million people worldwide. Symptoms include persistent fatigue, brain fog, pain and gastrointestinal problems. The cause is still unclear, though previous research has implicated gut bacteria, genetics, infections and even microscopic blood clots.

To investigate further, Brent Williams at Columbia University in New York and his colleagues analysed gut bacteria from stool samples from 106 people with ME/CFS and 91 people without. They found significant differences in the quantities of nine microbes.

One of the most notable was the bacteria *Faecalibacterium prausnitzii*. On average, people with ME/CFS had 35 per cent less *F. prausnitzii* than people who didn't have the condition (*Cell Host & Microbe*, doi.org/grq9x8).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People recently diagnosed with ME/CFS have less of the bacteria *F. prausnitzii*

Participants completed a survey measuring fatigue symptoms at the time of stool collection. Comparing these fatigue scores with stool samples revealed a strong association between reductions in *F. prausnitzii* and fatigue severity. Together, these findings suggest a lack of *F. prausnitzii* plays a role in ME/CFS.

"One of the underpinnings of this illness is the amount of inflammation that these patients have," says Nancy Klimas at Nova Southeastern University in Florida. *F. prausnitzii* is a main producer of anti-inflammatory molecules called short-chain fatty acids; having too little of it may contribute to excess inflammation seen in ME/CFS, she says.

Another study by Julia Oh at the Jackson Laboratory in Connecticut and her colleagues found similar associations. They analysed bacteria in stool samples from a separate group with ME/CFS, of whom 75 had been diagnosed with the condition in the last four years and 79 had been diagnosed more than 10 years ago (*Cell Host & Microbe*, doi.org/grq9vk).

They found that, on average, only those in the short-term group had significant decreases in microbes known to make short-chain fatty acids, including *F. prausnitzii*, compared with controls. Gut microbiomes of people in the long-term group closely resembled those of people without the condition.

One explanation could be that there is "an event happening early on in the disease process that eventually dissipates, but changed the gut environment", says Timothy Sampson at Emory University in Georgia. Many people with ME/CFS report that their symptoms began after a viral infection, for instance. "You can think of it sort of like a hit and run," says Sampson.

> "Having too little of this bacteria may contribute to the excess inflammation seen in chronic fatigue"

There are also other possible explanations. People recently diagnosed with ME/CFS are more likely to try unproven treatments, such as supplements, which could modify the composition of gut microbes, says Klimas. "Just because the microbiome is altered in a disease does not mean that the microbiome is contributing to the disease," says Sampson. ▮

Animal behaviour

Multiple tools help cockatoos get the job done

COCKATOOS can understand that they need to bring a two-piece "toolkit" to retrieve a cashew nut treat. This makes them only the second non-human animal, after chimpanzees, that seems to view multiple tools as being part of a set needed to achieve a single goal.

Goffin's cockatoos (*Cacatua goffiniana*) are small, white parrots from Indonesia. In captivity, the birds have been seen using three human-made tools to retrieve seeds from inside a fruit stone: one for cutting the stone, a sturdier tool for wedging open a crack and a third one for scooping out the seeds.

But it was unclear if the birds understand that all three items are part of a set or if they just used each tool in turn as the need arose, says Antonio Osuna-Mascaró at the University of Veterinary Medicine Vienna in Austria.

Osuna-Mascaró's team presented cockatoos with a cashew nut, held in a box behind a transparent cover. To get it, the birds first had to use a short, pointed stick to puncture the cover, then switch to a longer straw to retrieve the nut. Seven out of 10 birds worked out how to do this.

THOMAS SUCHANEK

A cockatoo using a sharp stick to puncture a cover concealing a reward

But did the birds see the two items as part of a set? To find out, five of the successful birds were tested again. This time, the team placed the box higher up than the offered tools, so the cockatoos had to make a short but arduous vertical flight to transport them. Four of the birds learned to take the two tools to the box in one trip (*Current Biology*, doi.org/jwbv).

"They are using the tools as something more than the sum of their parts," says Osuna-Mascaró. "Many animals use tools, but they use them in a rigid way depending on their innate behaviours. Other animals are able to use tools in flexible ways to solve novel problems."

"The Goffin's cockatoos are probably not unique [among birds] – it's simply that they have been studied," says Alex Kacelnik at the University of Oxford. ▮

Clare Wilson

Society

Lower incomes mean longer waits for basic services

Corryn Wetzel

PEOPLE in low-income households spend 6 hours more per year waiting for government services and healthcare than people from wealthier households in the US. Additionally, regardless of their economic status, Black people spend as much time waiting as those with lower incomes.

Stephen Holt at the University at Albany in New York and Katie Vinopal at The Ohio State University investigated how waiting times vary for different people using data from the US Bureau of Labor Statistics' American Time Use Survey, in which participants record a 24-hour time diary of their activities.

They found that people in households making less than $20,000 a year spend an average of 12 additional minutes waiting, on each day that waiting occurs, compared with those in households earning more than $150,000. Around a quarter of people in the US live in households in the lower-income group and 8 per cent in the higher-income group. "This is 6 hours a year not of waiting, but of additional waiting, just because you're low income," says Holt.

The pair also found that Black people are more likely to wait longer for services regardless of income status, and Hispanic people are more likely to wait for services than white people in the same income bracket (*Nature Human Behaviour*, doi.org/jwmb).

Waiting can be more than just frustrating. Delays in accessing medical care can lead to worse health outcomes. Long lines in grocery stores may prompt people to take fewer trips and purchase more shelf-stable, processed foods.

The additional waiting experienced by Black, Hispanic and lower-income people costs the US economy between $3.6 billion and $9.3 billion in lost productivity each year, the researchers estimate. ▮

Archaeology

Severe drought may have doomed the Hittite empire

Clare Wilson

BENJAMIN ANDERSON

The Lion Gate at Hattusa, the capital of the Hittite empire

A THREE-year-drought may have led to the fall of the Hittite empire in the Middle East 3000 years ago.

The finding comes from analysing timber used to make the burial chamber of a later ruler, who may have been the father of King Midas, referred to in Greek legends.

The sudden drought "would have undoubtedly caused mass problems with food provision. That would have affected the tax base of the empire pretty dramatically," says Sturt Manning at Cornell University in Ithaca, New York.

The Hittite empire, which encompassed most of what is now Turkey and lasted nearly five centuries, was one of the major geopolitical forces of the ancient world, with a mastery of ironwork, a cuneiform writing system and an army that could take on neighbouring Egypt.

Ancient texts and archaeological discoveries suggest that around 1200 BC, cities began being abandoned and the empire splintered into independent states that were later overwhelmed by Assyrians from the east.

Several causes have been proposed, including disease, famine and a centuries-long shift to a drier climate, as well as earlier invasions by mysterious groups named "Sea Peoples" in Egyptian texts.

Now, Manning's team has found evidence of a sharp and severe drought from a huge chamber tomb built in the city of Gordion in 748 BC. As the tomb's mound is much bigger than others nearby, and was made about the time the local King Midas took the throne, some archaeologists say it could have been made for Midas's father, the previous ruler – although nothing to identify the occupant remains.

1198 BC

Date when severe drought began, according to tree ring analysis

Clues to the fall of the Hittites, centuries earlier, come from the juniper logs making up the burial chamber. The logs were taken from 18 trees, which were growing from the period 1775 to 748 BC.

Less rainfall means less tree growth, which shows up as narrower gaps between tree rings. The logs show there were 80 instances of two or more consecutive years with low rainfall, and one of these was the three years from 1198 to 1196 BC – just when Hittite cities started being abandoned.

This was supported by another kind of test: measuring the ratio of different forms of carbon from samples of the wood. That showed gradually increasing dryness of the atmosphere between 1300 and 1200 BC, then spikes of dryness from 1222 to 1195 BC (*Nature*, doi.org/grq9wr).

"Most traditional societies had some storage that would have helped them through one bad harvest," says Manning. "By the time you get to a third one in a row, it's become a crisis."

Alan Greaves at the University of Liverpool in the UK, who wasn't involved in the research, says the results shed new light on the climate changes at the time and their economic impacts. "How do you pay for soldiers, how do you pay for artisans to make things?" he says. "A short, sharp drought would be enough to topple a very centralised state based heavily on grain and the gathering in and distribution of agricultural goods." ▮

Solar system

Dust ring orbits the sun with Mercury

MERCURY appears to share its orbit with a ring of dust millions of kilometres thick, and scientists aren't sure how it formed.

The dust ring was discovered in 2018. Petr Pokorný at the Catholic University of America in Washington DC and his colleagues investigated possible explanations for its existence. The only one that could explain the dust's presence was that debris was created within Mercury's orbit. The simplest way to produce such debris is through impacts with Mercury that throw dust and rocks off its surface.

But when they used data from the Messenger spacecraft to compare the mass of the ring with the estimated mass of ejected material from known large impacts, they couldn't produce enough dust (arxiv.org/abs/2301.10219). **Leah Crane**

Animal behaviour

Orca mothers care for their adult sons

OFF the Pacific coasts of the US and Canada, orca mothers provide food for their sons long after they reach adulthood, even though this restricts them from having more surviving offspring.

Michael Weiss at the University of Exeter, UK, examined data on 40 orca females from 1982 until 2021 and 54 calves that survived at least the first year of life. They then created computer models to look at the effects of male and female offspring on subsequent births.

The team found that in each year after giving birth to a male calf, mothers were 70 per cent less likely to bear a healthy, surviving calf again, compared with those that had borne a female calf. Even after their sons were fully grown, the mother's chances of successfully rearing another calf didn't go back up again (*Current Biology*, doi.org/grq9kz). **Christa Lesté-Lasserre**

PRAKASH MATHEMA/AFP/GETTY IMAGES

Climate change

Millions live in possible flood path for glacial melting

AS MANY as 15 million people live in areas that could be flooded by a natural dam failing at a glacial lake, according to the first global analysis of the hazard.

Tom Robinson at the University of Canterbury in New Zealand and his colleagues identified glacial lakes in satellite imagery. They then determined the number of people living within 50 kilometres of each lake, and within 1 kilometre of the river where water would flow in the event of a glacial lake outburst flood. These floods can happen when an ice or rock dam holding back a glacial lake fails, or a rock slide sends water sloshing over a natural dam.

The researchers found up to 15 million people could be affected, with 9 million in the Himalayas (pictured), 2.5 million in the Andes and 2.2 million in the Alps (*Nature Communications*, doi.org/jwbj). More than half of the 15 million live in either India, Pakistan, Peru or China.

Outburst floods are unlikely at many glacial lakes, and the study presents a simplified view of the areas any flooding would affect, says Simon Allen at the University of Zurich in Switzerland, but he says the global view helps draw attention to vulnerable and understudied regions.

Glacial lakes are growing rapidly in number and size as climate change melts more ice, but the frequency of outburst floods has decreased since the 1970s, says Stephan Harrison at the University of Exeter in the UK. As with warming after the 19th-century Little Ice Age, there may be decades of lag between warming and lakes growing large enough for an outburst, he says. **James Dinneen**

Really brief

SEVENTYFOUR/SHUTTERSTOCK

Raw food gives dogs healthier guts

Puppies that mainly eat dog food are more likely to develop problems with their gut health than those on a diet of leftovers or raw meat. This is according to a survey of more than 7000 dog owners in Finland about what they fed their pets over 10 years and the dogs' health (*Scientific Reports*, DOI: 10.1038/s41598-023-27866-z).

Loofah-inspired gel purifies water

A gel full of porous holes, inspired by the dried core of the loofah fruit, can clean contaminated water by absorbing and releasing it, powered only by the heat of the sun. It could be used to provide clean water in regions without a reliable electricity supply (*ACS Central Science*, doi.org/grrc2q).

Never-ending cities created for VR

An artificial intelligence can generate three-dimensional virtual models of cities that can grow to any size. This could be useful for producing virtual reality worlds or for training driverless cars to cope with new environments (arxiv.org/abs/2301.09637).

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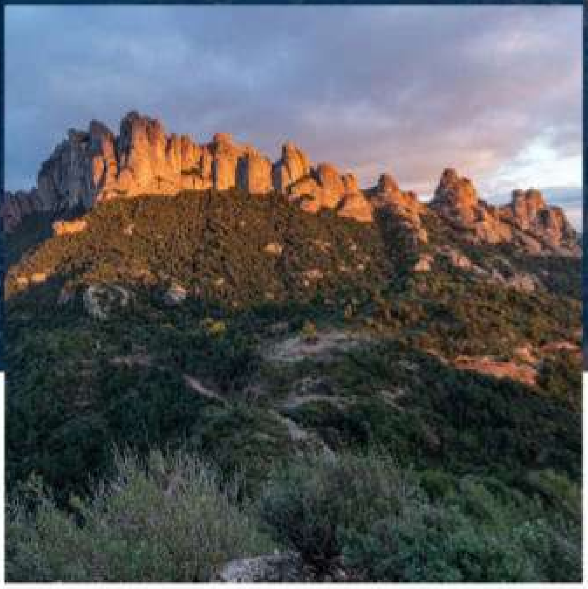

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Travel along backroads and through small towns to explore the landscapes, culture and gastronomy of the Catalan Pyrenees. The spectacular landscapes were formed by the collision of the Iberian Peninsula with Europe, and this tectonic impact is mirrored in the many cultural collisions that have occurred in the region, including colonisation by Romans, conquest by Muslims and the Frankish establishment of the Spanish Marches (Marca Hispanica), as well as the more recent Peninsular war and the Spanish civil war.

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Fukushima: the inside story of the ALPS treated water

ALPS treated water stored at the Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi Nuclear Power station is being prepared for discharge into the sea. The plan has the blessing of the international scientific community who say it is safe.

At the site of TEPCO's Fukushima Daiichi Nuclear Power Station, more than 1000 storage tanks hold purified water that has been put through the Advanced Liquid Processing System (ALPS) to remove radioactive contaminants. That's over 1.3 million cubic metres of water, enough to fill the Burj Khalifa in Dubai, the world's tallest building.

In 2021, the Japanese government announced its basic policy on the handling of this ALPS treated water, which is to discharge the treated water into the sea. The basic policy states the process used to treat and dilute the water makes it safe enough to meet international safety standards, except for tritium.

Most experts agree that when it is finally discharged, the water will pose little or no risk to human health or to the environment. When that happens, it will mark an important turning point in the decommissioning of the power station and for the reconstruction in Fukushima.

In the afternoon of 11 March 2011, a magnitude 9 earthquake rocked the east coast of Japan, the most powerful ever recorded in the country. It caused huge damage in the Tōhoku region in the north of Honshu Island.

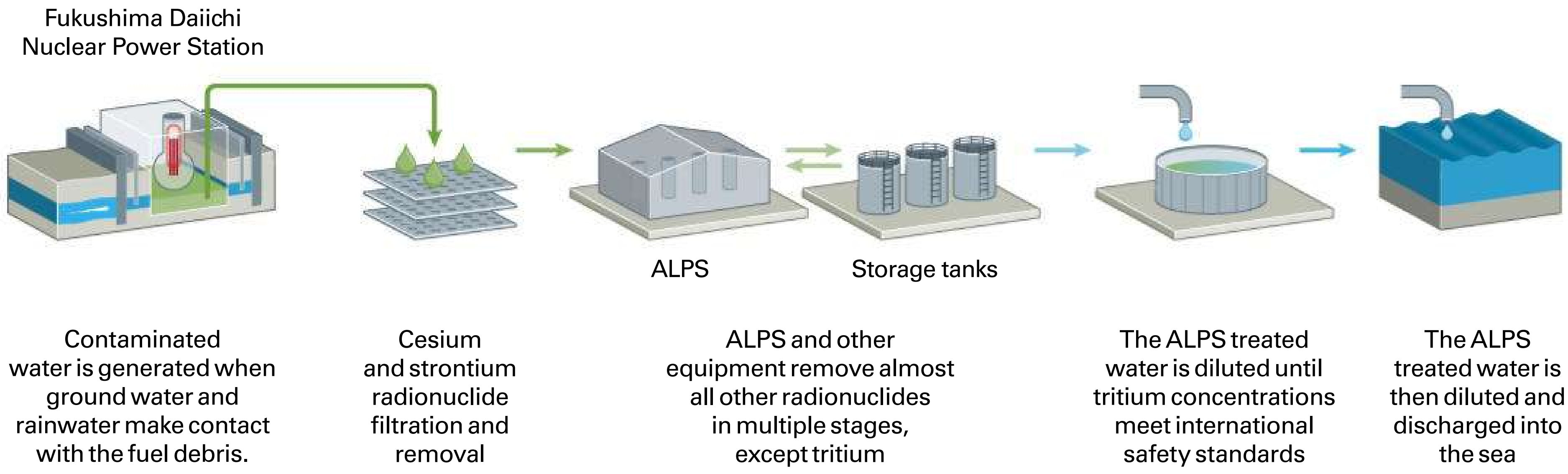
The earthquake also unleashed a tsunami that struck the coastal area of Tōhoku that same day. Over 19,000 people died in this double disaster although no one was killed by radiation.

The tsunami overtopped sea defences at TEPCO's Fukushima Daiichi nuclear power station, knocking out the backup power supply and the reactor's cooling systems. The reactors automatically shut down when they detected the earthquake, but the loss of the cooling systems caused havoc. Three reactors went into meltdown and hydrogen explosions of the reactor buildings released radioactive materials into the atmosphere and the ocean.

Due to the nuclear accidents, earthquakes, and tsunami, 165,000 people from the Fukushima prefecture had to be evacuated. In the aftermath, the Japanese government began a major project to decontaminate the area and rebuild the infrastructure. Since then, the reconstruction of Fukushima has progressed steadily. The area where people can return home has gradually expanded and today the number of evacuees has fallen to approximately 29,000.

However, there is a lingering task at Fukushima. The nuclear material inside the affected reactors needs to be cooled with a constant flow of water and this becomes contaminated with radioactive substances or "nuclides". The problem is made worse by rain and groundwater flowing into the buildings.

But engineers have fought back with various ingenious strategies, for example, by freezing the soil around the buildings to block the flow of groundwater. In May 2014, a daily average of 540 cubic metres of water was generated every day. By 2021, this had fallen


Fukushima Daiichi Nuclear Power Station
ALPS
Storage tanks
Contaminated water is generated when ground water and rainwater make contact with the fuel debris.
Cesium and strontium radionuclide filtration and removal
ALPS and other equipment remove almost all other radionuclides in multiple stages, except tritium
The ALPS treated water is diluted until tritium concentrations meet international safety standards
The ALPS treated water is then diluted and discharged into the sea

to a daily average of 130 cubic metres.

Soon after the accident, TEPCO began cleaning the water by filtering out radioactive cesium and strontium, two of the most common nuclides.

However, the water also contains many other nuclides. To manage this, TEPCO has developed an Advanced Liquid Processing System (ALPS) that can remove 62 different kinds of radioactive material from the water.

The idea is conceptually similar to a household water filter, but on a huge scale. The system pumps the contaminated water through a series of filters. These contain adsorbent materials that bind to the radionuclides. Because there are so many different nuclides, ranging from antimony to zinc, the water goes through multiple filters with different adsorbent properties.

“The Japanese government plans the discharge to begin in 2023”

By June last year, this process had generated 1.3 million cubic metres of ALPS treated water, which is housed in over one thousand tanks on the Fukushima Daiichi site.

Water which does not satisfy the regulatory standards for discharge into the environment, will be re-purified by ALPS or other equipment until the level of radionuclides satisfies the regulatory standards for safety, except for one nuclide that cannot be removed by ALPS : tritium, a form of hydrogen.

A normal hydrogen atom has a single proton in its central nucleus, but tritium also has two neutrons. These neutrons make the nucleus unstable and therefore radioactive. The problem is that tritium is chemically identical to hydrogen and very difficult to remove from hydrogen-bearing compounds such as water. Tritium exists naturally in sea water and even in the human body, albeit at low concentrations. These low concentrations are safe because tritium does not accumulate in the body.

That suggests a safe way to solve the tritium problem by diluting the water that contains it with ordinary seawater and then controlling the amount of discharge.

The Japanese government’s plan is to dilute the ALPS treated water over a hundred times. At the same time, they set the annual discharge limit of tritium below 2.2 trillion Becquerels which was the limit for discharges before the accident. The resulting liquid will have tritium levels of less than 1500 Becquerels per litre (2.5% of regulatory standards), some seven times lower than the World Health Organization’s guidelines for drinking water.

At this level, the international scientific community believes it is safe to discharge the water into the ocean. Indeed, many nuclear facilities routinely discharge tritium in similar ways, and sometimes at higher concentrations.

The entire clean-up and discharge process is being reviewed by the International Atomic Energy Agency (IAEA), part of the United Nations. The IAEA has repeatedly said that Japan’s plan is technically feasible and in line with international safety standards. In April 2022, the IAEA released its first report following its mission to Japan, the first of a series that will be conducted in future.

“Releasing into the ocean is done elsewhere,” according to IAEA Director General Rafael Mariano Grossi, speaking in 2021. “It’s not something new.” Other nuclear experts have backed this view. “The facts are not telling me that this is something that we should be very worried about,” said Jordi Vives i Batlle at the Belgian Nuclear Research Centre in Mol, in an interview that appeared in the science journal *Nature* in 2021.

The Japanese government plans the discharge to begin in 2023 and continue over several decades. The discharge will allow the Fukushima Daiichi nuclear power station site to be utilized in the most effective way during essential and most challenging decommissioning measures, such as removing fuels. The IAEA review will be conducted before, during, and after the discharge. It will be a long process but one that will finally put to rest some of the legacy of the Fukushima nuclear accident.

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Comment

No miracle required

A focus on revolutionary "green" technologies is slowing the uptake of existing solutions to problems such as climate change, says **Mark Jacobson**

MICHELLE D'URBANO

BILL GATES has put billions of dollars into new technologies he believes will help halt climate change: small modular nuclear reactors, biofuels, capturing carbon dioxide from fossil fuel facilities (carbon capture) or the air (direct air capture) and geoengineering (reducing solar radiation by adding particles to the atmosphere). ExxonMobil is building a "blue hydrogen" plant that produces the fuel from natural gas and tries to capture the CO_2 emissions. The US Inflation Reduction Act provides funding that Gates, ExxonMobil and other companies can use to capture CO_2. It also helps to fund Gates's dreams of small modular reactors and bioenergy.

The problem is that none of these technologies is useful for helping to solve the climate crisis, let alone the wider air pollution or energy security problems the world faces. We only have until 2030 to eliminate 80 per cent of the world's greenhouse gas emissions and until 2035 to 2050 to banish the rest to avoid 1.5°C of warming. Moreover, 7 million people die prematurely each year due to air pollution and hundreds of millions more become ill. About 90 per cent of this pollution is from energy. Lastly, the world faces several energy-security risks, including the instability that will result from fossil fuels and uranium running out.

Given the magnitude and urgency of these problems, the best solution is one that can be implemented quickly, at low cost, while tackling all three issues at once. However, almost all the technologies proposed by Gates and ExxonMobil, among others, don't attempt to address pollution or energy security – and they hardly help with climate change.

Carbon capture, direct air capture and blue hydrogen – which all require equipment and energy – increase air pollution, relative to using the same money to replace fossil fuels with renewables, while scarcely reducing CO_2. New nuclear plants have a 10 to 21-year time lag between planning and operation (too long to help solve the problems discussed here), costs that are five to eight times those of new wind and solar power per unit energy, and CO_2 emissions that are nine to 37 times those of onshore wind. Bioenergy produces air pollution and greenhouse gases while using rapacious amounts of land and water.

Rather than searching for a miracle, we need to look at the wind, water and solar technologies right in front of us. Combining these with energy storage, efforts to encourage people to shift the time of their electricity use to even out demand, a well-interconnected electrical transmission system to limit the problems of intermittent power supply from renewables, and efficient electrical appliances, such as heat pumps, will allow us to solve all three ginormous problems at low cost worldwide.

A wind, water and solar system would use much less energy than a combustion-based one. Globally, the energy that people use typically falls by over 56 per cent with these green technologies. On top of that, wind, water and solar reduce the cost per unit energy by another 12 per cent on average, resulting in a 63 per cent lower annual energy bill worldwide.

The global upfront capital cost of building such a system by 2050 is around $62 trillion. However, due to the $11 trillion annual energy cost savings, the payback time is less than six years.

What is more, we already have 95 per cent of the technologies we need to solve all three problems. So we don't require "miracle" technologies. To solve our problems, we need to avoid policies that divert funds from true solutions. We must educate the public and policy-makers about what works and what doesn't, and thus overcome the misinformation that has distracted us to date. ▮

Mark Jacobson is a professor of environmental engineering at Stanford University. His new book is *No Miracles Needed*

This changes everything

Old connections A telecommunications museum in Seattle, with a working exchange from the 1940s, shows how telephones brought us together – but also tore us apart, says **Annalee Newitz**

Annalee Newitz is a science journalist and author. Their novels include *The Future of Another Timeline* and they are the co-host of the Hugo-winning podcast *Our Opinions Are Correct*. You can follow them @annaleen and their website is **techsploitation.com**

I STOOD inside a warehouse, sandwiched between two floor-to-ceiling frames that looked like ancient bookshelves or perhaps server racks from another planet. Their surfaces were alive with chattering metal switches attached to wires so old their plastic sleeves had faded to brown. It felt like I was trapped in a machine from a Charlie Chaplin movie. But I was actually in the guts of a Number Five Crossbar Switching System (5XB), developed at Bell Labs during the 1940s to route thousands of phone calls at once. The sounds I heard were numbers cascading through electrical switches mounted on crossbars, establishing a connection between two phones.

The 5XB is just one of many treasures at the Connections Museum, set in a working telephone exchange in southern Seattle and devoted to the history of telecommunications. There, you can make phone calls using technologies that date back more than a century. I was struck by the way these systems had begun as rugged components designed for the outdoors, which, over time, became looms of delicate wire.

One display showed linemen from 1900 in cowboy clothes, cable cutters in holsters on their belts, wearing badges that read "The Pacific Telephone and Telegraph Co". These men were often working in the wilderness, running wires between posts made from recently felled trees. Phone calls used to be something that required a bit of effort. I got to sit at an old PBX, or private branch exchange, and plug fat wires into the light-up switchboard to complete a call.

Next to the PBX was a massive Strowger Automatic Exchange from the 1900s, which replaced human operators with a machine whose switches were rotary-dialled, spinning on shafts until they found the right connection. The exciting thing about the 5XB was that it could route a call, establish a connection on a separate line and then route another call immediately. That meant the exchange went from being a connector to a service that provided routing. Millions of calls could surge through these 5XBs during their lifetimes, until most of them were retired in favour of computerised exchanges in the 1990s. Today, some of those modern exchanges occupy just one-and-a-half floors at the Connections Museum. They may take up less space, but they don't provide the visceral satisfaction of seeing an actual circuit being made, the phone numbers clicking across the thumb-sized switches.

> **"Seeing an old exchange is a way to appreciate how our ancestors refined the 20th century's greatest tools"**

It made me think about another tech preservation project I had come across by accident, hiking the trails around Bolinas and Point Reyes Station in northern California. There, I stumbled across the hulking skeletons of two early 20th-century radio transmitter-receiver stations that are landmarks in the development of wireless technology.

In 1913, electrical engineer Guglielmo Marconi's radio firm planted several 90-metre towers in the coastal farmland of Bolinas to form an enormous antenna array for broadcasting across the Pacific. A similarly sized radio receiver is found a few kilometres north at Point Reyes Station. Though originally intended to bring nations together with instant voice communication, both were taken over by the US government after the first world war. They became Radio Corporation of America (RCA) stations, tasked with sending transmissions to warships in the Pacific. The facilities are rural – cows graze between towers – and feel nothing like a modern radio station with its tidy banks of digital readouts.

Today, the RCA facility at Point Reyes still hosts tours and the local Maritime Radio Historical Society does regular broadcasts using the equipment there. Getting dirty on a hike to see them is a poignant lesson that cutting-edge tech isn't always built in clean rooms with robots that paint molecule-thin circuits atop silicon wafers. Seeing a giant old telecom exchange or radio receiver in person is a great way to appreciate how our ancestors refined the 20th century's greatest tools.

But the experience also offers valuable cultural context for the mobile devices in our pockets. Here in the US, long snakes of wire nailed to poles helped settlers conquer the West, allowing rapid communication between US militias intent on wresting land away from Indigenous nations and tribes. Telephones and radios brought us together, but they also ripped us apart. Perhaps it should be no surprise that the internet – built on the infrastructure that linemen laid down in the 1800s – has brought with it a new wave of horrific destructiveness.

History itself is a kind of transmission, broadcast to us in frequencies that become harder to receive as we forget the old ways. But as long as we keep the antique exchanges running, we have a way to remember and understand where we come from. ▮

Annalee's week

What I'm reading

Meru *by S. B. Divya, a very human story about friendship and coming of age in a post-human future.*

What I'm watching

Jung_E, *a mind-bending Korean sci-fi movie about a scientist trying to create a cyborg supersoldier using her mother's uploaded brain.*

What I'm working on

A short story about what happens after nuclear disarmament.

This column appears monthly

New Scientist
Events

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Julie Seibt
Senior Lecturer in Sleep and Plasticity, Surrey Sleep Research Centre

Anil Seth
Professor of Cognitive & Computational Neuroscience (Informatics), School of Engineering and Informatics, University of Sussex

Manos Tsarikis
Professor of Psychology, Royal Holloway, University of London

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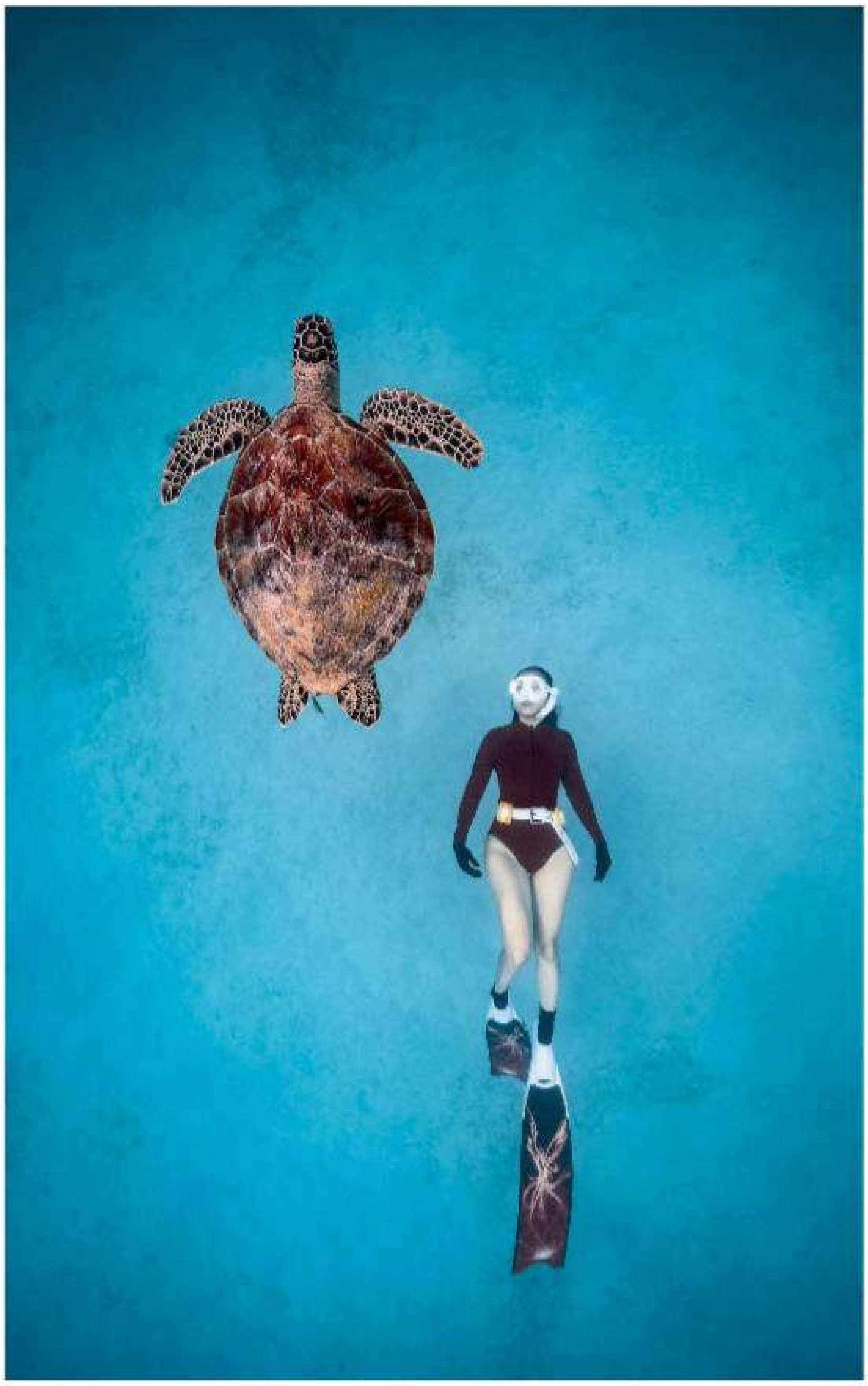


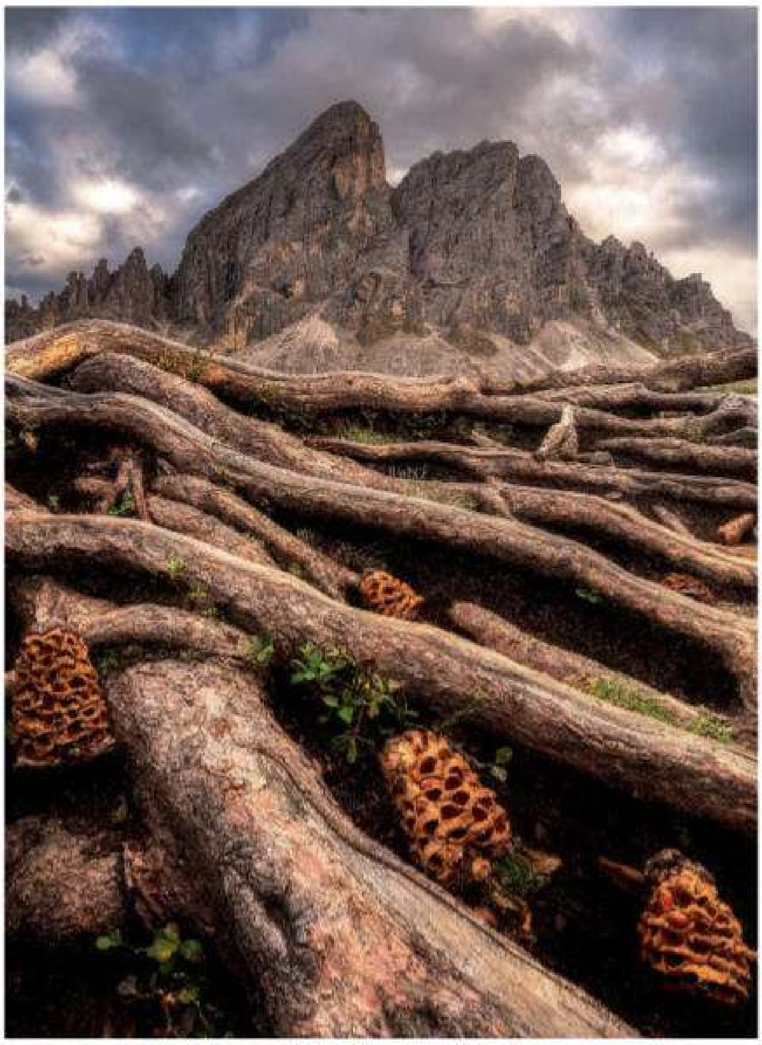
THIEN NGUYEN NGOC, VIETNAM, WINNER, NATIONAL AWARDS

PROTAP SHEKHOR MOHANTO, BANGLADESH, WINNER, NATIONAL AWARDS

MANUEL RODRÍGUEZ, COSTA RICA, SHORTLIST, LATIN AMERICA NATIONAL AWARDS

HUAZHENG HONG, SINGAPORE, WINNER, NATIONAL AWARDS

ANDRES NOVALES, GUATEMALA, SHORTLIST, LATIN AMERICA NATIONAL AWARDS



VLATKO RAFESKI, NORTH MACEDONIA, SHORTLIST, REGIONAL AWARDS

Nature's finest

World Photography Organisation
Sony World Photography
Awards 2023

THIS spectacular selection of images embodying nature's grandeur and variety are among the best of the bunch in the 2023 Sony World Photography Awards competition, open to entries from many corners of the world.

For the Vietnam category, Thien Nguyen Ngoc took first place for his tranquil shot of a sea turtle and diver swimming together in harmony off the coast of the Perhentian Islands, Malaysia (top left). Below it is the winning entry for Bangladesh – the yellow eyes of a spotted owlet peeping out from its tree trunk nest in the country's National Botanic Garden, taken by Protap Shekhor Mohanto.

Another dramatic eye features in the top centre image, this time belonging to a red-eyed tree frog in its Costa Rican rainforest home, which saw Manuel Rodriguez shortlisted in the Latin America category. Andres Novales from Guatemala also made this shortlist for his ominous shot (top right) of a crocodile on the muddy banks of the Usumacinta river, taken towards the end of Guatemala's rainy season. It is a reassuring sight, since crocodiles are a key indicator of a healthy ecosystem.

The awards also gave a nod to some dazzling natural scenery. The image at bottom centre by Huazheng Hong is the Singapore winner. He captured the immense scale of the Ilulissat icebergs off Greenland. To the right of this is a shortlisted shot by Vlatko Rafeski of North Macedonia. It is from the Dolomites mountain range in Italy, showing the two-headed peak of Peitlerkofel in the background.

An exhibition of the awards will run at Somerset House, London, from 14 April to 1 May. ▮

Gege Li

Editor's pick

Long-haul flights can be justified in climate fight

3 December 2022, p 28

From Shawn Charland, Ottawa, Canada

I was interested to read about Graham Lawton's life-affirming trip to see research work in Uganda. He mentions the climate crisis and his guilt about the long-haul flight required to get there. The balance of the piece cogently explains the steep scientific cost if research communities were to adopt a moratorium on long-haul flights.

Here is another strong argument in favour of that view: the calculus of solving the climate crisis isn't a zero-sum game. It is perfectly permissible, and sometimes necessary, for people who promote awareness and urgency of the climate crisis, and who lobby for solutions, to take long-haul flights. The benefit can outweigh the cost.

If one person took a long-haul flight to a conference that convinced 10,000 people not to drive their cars, that would be a brilliant win.

On the idea that there is a mirror universe

28 January, p 38

From Ray Cannon, Camberley, Surrey, UK

Since antimatter is identical to matter flowing in the opposite direction through time, my assumption is that the mirror universe is filled with antimatter. So, a key question posed for our universe – "where has all the antimatter gone?" – is answered.

From Adam Huntley, St Albans, Hertfordshire, UK

Knowing the scientific world's love for new names to describe its shiny new concepts, it is surely just a matter of time before the mirror universe gets this treatment. Perhaps it will become known as the "mirroverse" or maybe the more accurate "biverse"?

From Mike Phair, Redmond, Washington, US

Will our universe and the mirror universe ever stop expanding away from each other and instead start accelerating back together, perhaps due to some underlying force of attraction between the two? Might a collision of these universes lead to a so-called big crunch scenario, spawning another big bang?

Could melting robot be a sign of things to come?

4 February, p 12

From HildaRuth Beaumont, Brighton, UK

In the movie *Terminator 2: Judgment Day*, the villain of the piece is the T-1000, a killer robot composed of a shape-shifting metal alloy. There is clear resonance here with the robot created by Carmel Majidi and his colleagues. Is this a case of science fiction in the process of becoming science fact?

All the things the aether theory did for science

28 January, p 54

From Dave Tarpley, Concord, California, US

Reader Nick Canning says the aether theory was "ascientific".

However, this theory was one of the most fruitful in the history of science. It was useful during the development of electrodynamics, allowing James Clerk Maxwell to perceive light as electromagnetic. Mathematical and mechanical models of the aether enabled physicists to study the subject.

It is because aether theory was so rigorous that it eventually ran into trouble. By the 1890s, with the discovery of the electron, it was clear that a wholly mechanical explanation of electromagnetism was all but impossible.

Too premature to think of banning gas stoves

21 January, p 17

From Liz Tucker, London, UK

I understand the health and ecological problems with gas stoves that are concerning authorities in the US, but it seems unrealistic to ban them in favour of electric stoves. In the 1970s, my flatmates and I would huddle round the gas oven to keep warm during power cuts. Amid warnings of power cuts in the future, it seems unwise to put all our eggs in one basket.

A wise Bigfoot may choose to steer clear of bears

4 February, p 11

From Bryn Glover, Kirkby Malzeard, North Yorkshire, UK

It occurred to me on reading your report about Bigfoot sightings correlating with higher numbers of black bears in the US that if I belonged to a small, endangered family group of surviving Sasquatch, the last place I would choose to live would be somewhere that is rife with competing bears.

Mars study provides a welcome alternative

7 January, p 13

From Natalie Roberts, Watford, Hertfordshire, UK

You report that a small base of six people at the Martian poles could support themselves energy-wise with a combination of solar power and well-placed wind turbines.

This should come as a relief to anyone who has read *How To* by Randall Munroe. In the chapter "How to Power Your House (on Mars)", he points out that conventional sources are absent or won't work as well. So, he adapts an old idea to make use of Phobos, a Martian moon. All that is needed, he points out, is a 5820-kilometre tether dangling from the moon into Mars's atmosphere, with a "turbine 20 metres in diameter" at its end. This would generate enough energy to power a town.

Munroe mentions a downside: Phobos is edging closer to Mars, and drag from the turbine would speed this process by an unknown amount, hastening disaster.

Database of essays could head off ChatGPT cheats

21 January, p 15

From Colin Sutton, Sydney, Australia

If the OpenAI company recorded all the responses its ChatGPT AI sent to students who get it to write their homework, it could easily provide a service for schools to check their essays. This might allay fears that it will be used to cheat.

Remember, AI is fixing bugs in our fallible code

4 February, p 16

From Paul Bethel, London, UK

In your look at how the AI ChatGPT is being used to find and fix bugs in computer code, I had to chuckle at the quote: "We don't want to rely totally on the AI as it is not infallible." Unlike humans?

Come to Houston and buy a bag full of human waste

28 January, p 17

From Dave Dyer, Houston, Texas, US

Your story on the potential for using human waste as fertiliser is a bit late. Houston has been bagging up our dried sewage and selling it as fertiliser under the name Hou-Actinite for decades. It is recycled, natural and all organic! If you ever come to Texas, I can show you where to buy a sack. ▮

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Don’t use the Q word

From love to cancer cures, the word “quantum” has been hijacked. This book arms us all against hawkers of quantum rubbish, finds **George Bass**

Opportunism might be an inevitable cost of quantum technology

WONG YU LIANG/GETTY IMAGES

Book

Quantum Bullsh*t

Chris Ferrie

Sourcebooks

QUANTUM threads are said to connect us to the fabric of space-time and serve as a conduit for the universe’s energy. It is enough to make Chris Ferrie, a quantum theorist at the University of Technology Sydney, rage. Firstly, because quantum threads don’t actually exist, and secondly, because they are a clear example of his field of research being hijacked by opportunists keen to attach the word “quantum” to their product.

*Quantum Bullsh*t: How to ruin your life with advice from quantum physics* offers readers the same playful exploration that Ferrie’s *Newtonian Physics for Babies* brought to 3-year-olds – but with much more colourful and less publishable language.

He takes aim at the kind of “profound sounding” quantum nonsense found on websites offering “access to the quantum universe via ‘meditation, hypnosis and credit card transactions’ ”. This could seem like a turkey shoot, but a few minutes on the internet provides Ferrie with ample justification.

Take the Quantum Xrroid Consciousness Interface, which claimed to use quantum energy to treat conditions including cancer. Though widely debunked, it is still being sold online. And when Ferrie simply types his job title into a search engine, he receives offers on crystal bibles that catalogue “new generation, high-vibration stones for healing and transformation”.

Ferrie places a moral question mark over articles covering such oddities as “quantum love”, and others that combine particle physics with the *Kama Sutra*. These turn out to be written by researchers with doctorates.

What elevates Ferrie’s book beyond a mere takedown of quantum quackery is how the author implicates his fellow physicists in some of the quantum BS. From early arguments about superposition to Albert Einstein’s conviction that God doesn’t play dice with the universe, all the way to current arguments over string theory, lack of agreement could explain why so many hawkers have moved in.

> **“The author asks if it might have been smarter to write a quantum vegan cookbook”**

“Western culture has a love-hate relationship with science,” Ferrie observes, an ambivalence to progress unless it confirms our biases or saves our lives. Yet upcoming quantum technology must be “built up slowly and carefully through international collaborations of scientists”, he writes.

There may well be no way, explains Ferrie, for this kind of cutting-edge science to avoid opportunism and frankly odd speculation. He recounts how, when the first mechanical clock was invented, people argued about whether the human brain was in fact connected to the body in a cog-like fashion.

Quantum physics, he explains, is particularly attractive to opportunists because it seems to fly in the face of the idea of the universe as a series of interconnected systems – leaving a lot of room for invention.

Ferrie’s own scientific explanations are couched in humour. “I have to listen to you drone on about your yappy little dog and keto diet,” he writes under one set of figures. “So you are going to listen to me about this one tiny math equation for five goddamn seconds.”

He also offers some easy-to-follow explanations of the value of joules, sound wave patterns, Niels Bohr’s correspondence principle and why quantum power definitely isn’t a mystical energy that only a select few can harness.

Readers will emerge infinitely more protected against quantum BS than the many who have only seen or heard glancing references to it on the internet. That said, while Ferrie sticks to his task of debunking and clarifying throughout the book, at one point he asks himself whether it might have been smarter to write a quantum vegan cookbook instead.

Perhaps he would have become richer, and that version of him may well exist in one of the parallel universes outlined in his explanation of the many-worlds interpretation.

In this reality, however, we would do well to follow Ferrie’s advice and stick to more proven examples of quantum technology, such as MRI machines and telescopes that allow us to see deep into the cosmos. ▮

George Bass is a writer based in Kent, UK

Lost in space

A new documentary highlights the psychological costs of our efforts to explore the solar system, finds **Katie Smith-Wong**

Film

The Longest Goodbye
Ido Mizrahy
Sundance Film Festival premier

AUTOMATION and artificial intelligence in space missions are still a long way from being able to do everything required for success – to a greater or lesser extent, humans are still required. But with crewed lunar and Martian flights on the cards in the near future, what is the psychological effect of astronauts spending months in extreme, confined environments without much or any contact with friends or family?

This is the central question Ido Mizrahy explores in *The Longest Goodbye*. Drawing on interviews with psychologists and human behaviour specialists, plus former astronauts and their relatives, his documentary also delves into NASA's efforts to maintain morale and deal with obstacles caused by prolonged separation in the lead-up to the SpaceX Crew-3 flight to the International Space Station (ISS) in 2021. Overall, the documentary succeeds in painting a moving picture of the emotional and mental turmoil astronauts feel while away from Earth, and what is being done to make space exploration a more tolerable job.

Gone are the days of John Glenn and the Friendship 7 capsule, when nations competed just to get people into orbit for a few hours. With Mars in NASA's sights, crews flying there will face months in deep space and even the most successful applicants will have to undergo psychological preparation that brings a risk of being deemed unsuitable to travel. There is also the lingering fear that such ambitions can come with a huge price: missing out on some of life's big events and risking the deterioration of relationships with family and friends.

Increasingly, space sci-fi – think Alice Winocour's *Proxima* or Ridley Scott's *The Martian* – is moving past the technical and wondrous side of space travel to reveal what the isolation does to astronauts and to their families and children back home. Psychologists such as Al Holland at NASA's Johnson Space Center in Texas bring an in-depth perspective to NASA's recognition that such missions are an intensely human business.

These specialists offer Mizrahy intriguing insights into how long-term isolation affects astronauts, showing a different side to one of the riskiest careers. They reiterate the importance of social contact and a support network wherever you are. As Holland says, bluntly: "If you are going to disconnect completely, you're not just lost in space, but lost on Earth."

***The Longest Goodbye* also provides a perspective that comes from having lived through this. Former US astronaut Cady Coleman, who had a long stint on the ISS that ended in 2011, is particularly candid about the struggles of space travel. We see her try her best to maintain a maternal presence while in orbit through online chats and even musical duets with her son at home. These don't prevent a tension she couldn't assuage, but they are the moments that will resonate with audiences as they show what can happen if a loved one is out of reach.**

Although it mostly comprises interviews, news coverage and behind-the-scenes footage, this documentary offers simplistic yet beautiful visuals that don't overwhelm the poignancy of its subject. Even when the film shifts focus to the most modern technology used to help maintain communications and acquires a futuristic aesthetic that will resonate with sci-fi fans, the human factor is never far away.

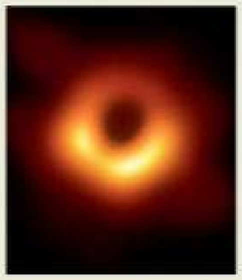
There is a thoughtfulness and humanity that drives *The Longest Goodbye*. Mizrahy's combination of candid insights, ambient soundtrack and gorgeous visuals provides him with the tools for a melancholic, profound appreciation of the human aspect of space exploration. ▮

Katie Smith-Wong is a film critic based in London

Astronaut Cady Coleman is open about the difficulties of losing vital connections with Earth

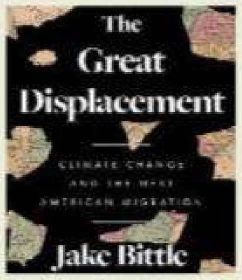
NASA/BILL INGALLS

Don't miss



Visit

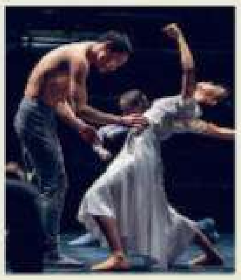
Echoes from the edge of space and time is a talk by Ziri Younsi, one of the team to take the first picture of a black hole (above) using the Event Horizon Telescope. At the Royal Institution in London at 2pm GMT on 25 February.



The Great Displacement
Jake Bittle

Read

The Great Displacement is Jake Bittle's compassionate account of the human geography of the US, as climate chaos displaces families, homesteads and whole communities, and states struggle to respond. On sale from 21 February.



Watch

Creature is a ballet adapted for film by Asif Kapadia, inspired by Georg Büchner's *Woyzeck* and Mary Shelley's *Frankenstein*. Creature (Jeffrey Cirio) is altered to withstand cold and isolation. In cinemas from 24 February.

LOWER: BFI DISTRIBUTION & ENGLISH NATIONAL BALLET; UPPER: ESO

The TV column

Identity crisis

Jack Billings is selling holiday homes on the moon in Apple TV+'s latest science-fiction show, *Hello Tomorrow!* But this is no paean to shiny robots or hover cars, more a mid-20th century social drama, finds **Bethan Ackerley**

Bethan Ackerley is a subeditor at *New Scientist*. She loves sci-fi, sitcoms and anything spooky. She is still upset about the ending of *Game of Thrones*. Follow her on Twitter @inkerley

TV

Hello Tomorrow!

Amit Bhalla

Lucas Jansen

Apple TV+

Bethan also recommends...

TV

Fargo

Noah Hawley

FX

Each season of the show (based on the 1996 film) is set in a different year, but all involve murder and mayhem in the US Midwest. It kicks off with the story of a salesman with a dark secret.

Happy Valley

Sally Wainwright

BBC1

Happy Valley *is essentially a western transported to the UK's Yorkshire Dales. Each season features a spineless man embroiled in crimes that snowball out of control.*

APPLE TV+

Myrtle Mayburn (Alison Pill) has big doubts about her lunar holiday home

THERE is a certain school of thought that says "real" science fiction must be full of ideas about how science and technology might change our world. This is often called "hard" sci-fi, and there are those who view any deviation from this style with as bellicose an attitude as possible.

I am not a purist: I prefer to think of sci-fi as a broad church, with the power to imagine almost anything, even the traditional. This is something to bear in mind when watching *Hello Tomorrow!*, a new entry in Apple TV+'s growing roster of sci-fi shows.

It stars Billy Crudup as Jack Billings, a telegenic travelling sales rep and regional manager of Brightside, a company that builds holiday homes on the moon.

Set in a retro-futuristic US where the 1950s never ended, Jack and his team trawl for customers in a Stepford-style suburbia with hover cars, mechanical helpers and personal jetpacks. It is a mid-20th century, "atompunk" aesthetic most famously seen in later instalments of the *Fallout* video game series, and every gleaming robot and self-knotting tie screams "this is a sci-fi show".

But, for the most part, that is where its hard sci-fi credentials end. Look past the setting and it is clear that this is a familiar story of family, moral responsibility and the American dream. Jack was born to sell, unafraid to deceive his customers with fake moon rocks and pre-recorded calls from celebrity clientele, but he believes he is saving lives with his message that a better life awaits off-world.

> "I prefer to think of sci-fi as a broad church, with the power to imagine almost anything, even the traditional"

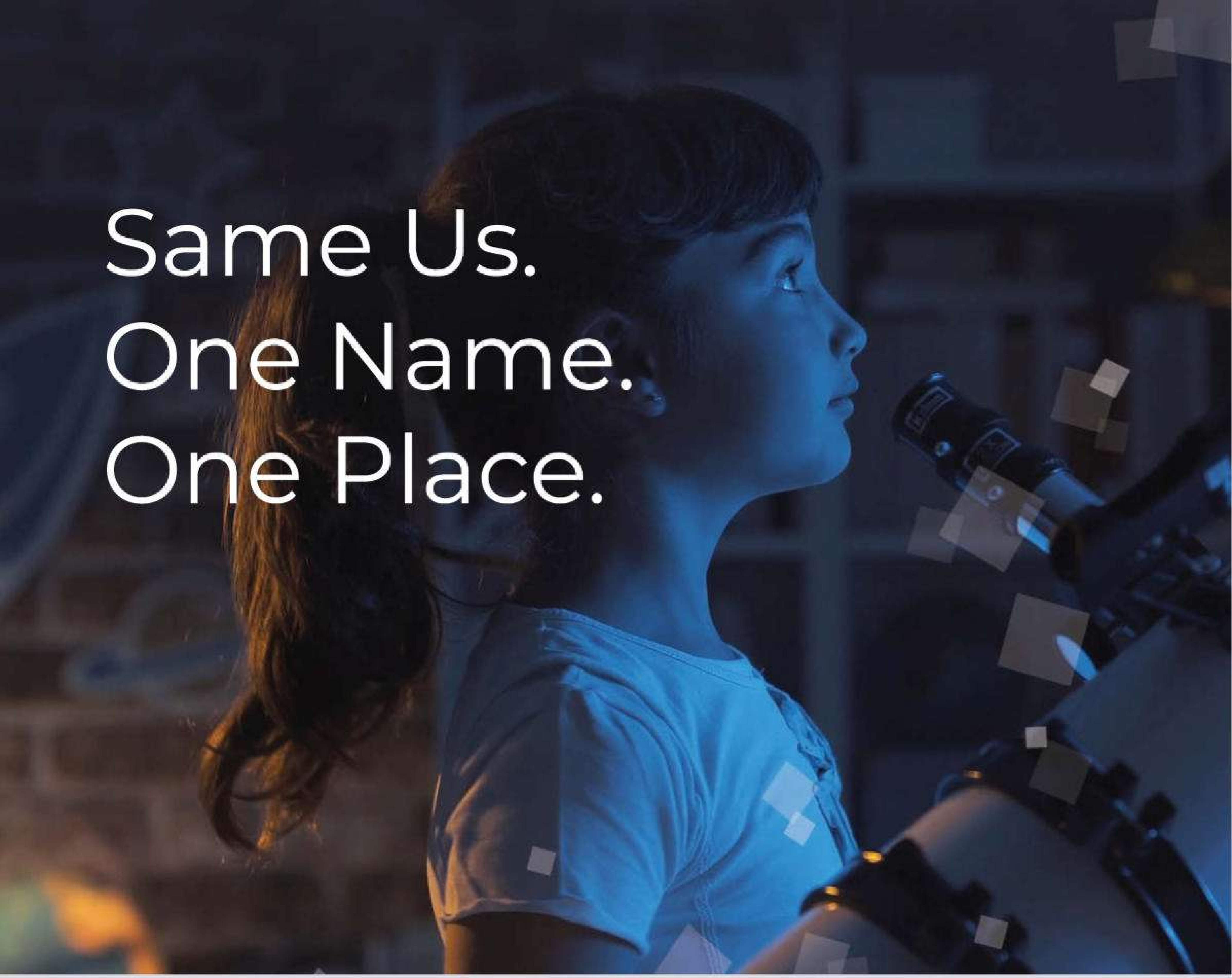
While visiting his mother, Jack learns that his estranged wife Marie (Annie McNamara) was hit by a self-driving hover truck and is now in a coma. Their 19-year-old son Joey (Nicholas Podany), who has no memories of his long-absent father, happens to attend a Brightside sales meeting and purchases his own lunar home, throwing him back into Jack's orbit. When faced with an opportunity to reconnect with his son, Jack does what comes naturally to him: he lies, offering Joey a job as a Brightside sales rep rather than revealing their history.

The show's thoughts on tech extend only to how a generation of workers might be rendered obsolete and in need of something to inspire them. In fact, *Hello Tomorrow!* is closer to an Arthur Miller play, albeit with added levity. Jack sits somewhere between Willy Loman in *Death of a Salesman* and Joe Keller in *All My Sons*: wistful, yet duplicitous; pitiable, yet charming. And with a theatre veteran like Crudup in the lead role, it is difficult not to see the series as a compelling social drama, particularly once Jack's lies begin to spiral out of control.

The larger mystery of what is really going on at Brightside is also intriguing. As more and more launches to the moon are delayed, other characters, such as Jack's second-in-command Shirley (Haneefah Wood) and aggrieved customer Myrtle Mayburn (Alison Pill), begin to question how luxurious lunar life really is.

That said, the show takes its time to get going, and it wasn't until the sixth episode that I was hooked. It doesn't help that there are many side plots involving the Brightside team to get through.

For some, *Hello Tomorrow!* will disappoint simply because it is the wrong kind of sci-fi. But, by setting a series about obsolescence and identity in a retro-futuristic world, the creators of *Hello Tomorrow!* have stumbled on a surprisingly potent result: a series greater than the sum of its genres. ▮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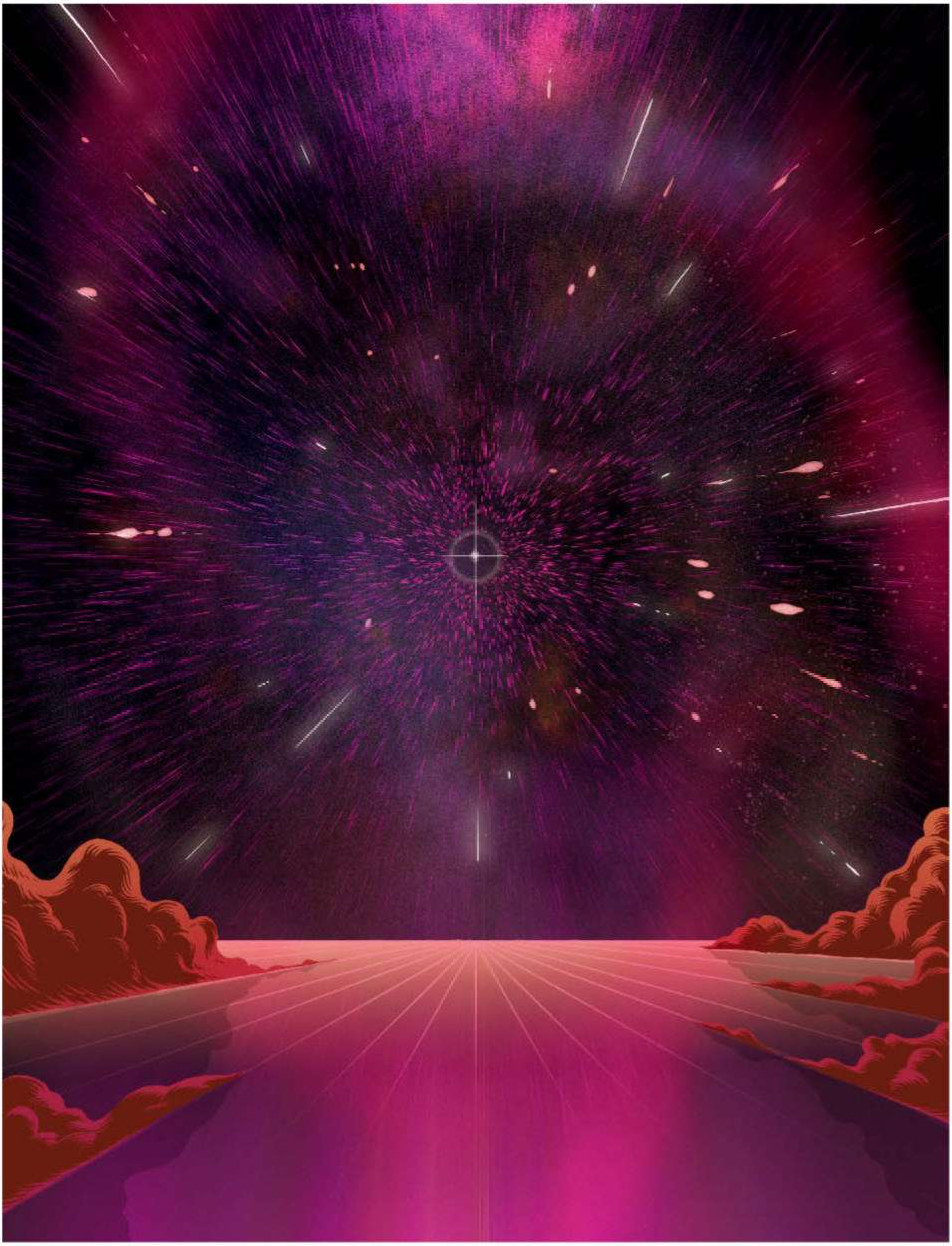

JOE WILSON

Into the void

Far from being irrelevant nothingness, interstellar space is fizzing with activity that could have huge implications for life as Earth traverses it. **Jonathan O'Callaghan** reports

THE jokes came easily for Thomas Bania when he began studying the properties of the empty space beyond our solar system. "I remember the look on my father's face when I was in graduate school," he says. "I told him I was an expert in nothing."

Most of us can see why Bania's dad hesitated over his son's choice of specialism. The exciting bits of the universe are the shining stars, the exotic planets, the icy comets. Isn't interstellar space just a featureless void – and so far away as to be tough to study anyway?

Not so. All the atoms in the universe's stars and planets account for only a piffling 4 per cent of its regular matter. The rest is spread out thinly in the gaps between the stars, in interstellar and intergalactic space. By that measure, what we normally think of as "empty space" isn't nothing – it is almost everything.

Over the past decade or so, researchers like Bania have been showing that interstellar space is deeply fascinating. This so-called nothingness is brimming with exotic molecules, pulsating with radio waves and divided into gigantic bubbles, each with their own character. Now, as we are beginning to map out our place within the void more keenly, we are coming to see that this variety matters immensely – and that as the solar system heads towards a new region of interstellar space, there could be important ramifications for life on Earth.

We are used to living in a thick soup of atmosphere. In a cubic centimetre of air, a volume the size of a six-sided dice, there are trillions of atoms. Gas, dust, water vapour, viruses, pollen and more all waft around. Just beyond our atmosphere, however, in interplanetary space, the conditions are close to a perfect vacuum. "Space is huge, and it's mostly empty," says Seth Redfield at Wesleyan University in Connecticut. Out there, the same volume contains, on average, just five atoms.

This matter mostly consists of charged particles streaming out from the sun as the solar wind. We have known for decades about this flow of material and how it creates a protective zone around the solar system called the heliosphere. It cocoons us from high-energy cosmic rays shooting at us from deep space – and a good thing too, because those rays can damage the cells and DNA in living things. Radiation levels are eight to 10 times higher outside this zone. "Without our heliosphere, would life even exist?" asks Jamie Rankin at Princeton University. Much about this crucial zone remained a mystery for a long time, though, not least where it ends and where interstellar space begins.

> "What we think of as 'empty space' isn't nothing – it is almost everything"

That changed thanks to two space probes, Voyager 1 and 2. They both launched in 1977 and were sent on different trajectories, with the principal aim of exploring the outer planets of the solar system. But once they had flown past them, they kept on going towards the inky blackness of interstellar space. In 2012, Voyager 1 recorded a huge drop in the strength of the solar wind and a simultaneous rise in the number of incoming cosmic rays. This occurred at 122 astronomical units (AU) from the sun (one AU is the distance between Earth and the sun, about 150 million kilometres). This, scientists later declared, was the heliopause, the edge of the heliosphere. Voyager 2 had taken a longer route heading out at a slightly different angle to its twin, but, in 2018, it also detected the heliopause at a similar distance from the sun.

At the heliopause, the interaction of the outflowing solar wind and the incoming interstellar medium results in temperatures of tens of thousands of degrees Celsius, causing particles to move at high velocity. But the sparseness of matter here – barely a single atom per cubic centimetre in the interstellar medium – means you would still freeze to death. That is because in order to heat anything up, particles would have to collide with it, and with so few particles, that would take an awfully long time. The density of matter out here is equivalent to "an orange inside the volume of Earth", says Bania. "The very best laboratory vacuums we can produce are a million times denser."

There are still many mysteries about the heliopause, though. For instance, when researchers analysed data sent from Voyager 2 in 2019, they found it appeared to have a smoother passage through a thinner section of heliopause than Voyager 1. We don't know why.

Then there is the more fundamental question of the shape of the heliopause. Our solar system is moving through the surrounding interstellar medium, which pushes against the heliosphere and distorts it. For this reason, the leading nose of our heliosphere is widely agreed to be rounded. But the shape of its "tail" remains controversial. Many favour a simple teardrop form. However, astronomer Merav Opher at Boston University in Massachusetts and her colleagues have been working on a NASA-funded project called Shield, using data from observations of the heliosphere to build computer models of it. This work led Opher to argue in 2021 that the heliosphere is shaped like a croissant,

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NASA/ESA/HUBBLE HERITAGE TEAM

with a two-pronged tail. With more probes designed to observe the heliosphere set to launch in the coming years, Opher reckons the question could finally be settled.

As well as finding out where interstellar space starts, we are discovering more and more about what it contains. We know there is a scattering of atoms and dust and that the density of this medium can vary considerably throughout our galaxy. "If interstellar space were uniform and smooth, it'd be much less interesting," says Bruce Draine at Princeton University. It was always thought, however, that complex molecules couldn't exist in interstellar space, as they would surely be ripped apart by the barrage of powerful cosmic rays.

Ingredients of life

But in 1970, astronomers Robert Wilson and Arno Penzias – famed for their accidental discovery of the cosmic microwave background radiation, the afterglow of the big bang – saw a signature of carbon monoxide in the Orion nebula, a gas-rich region of our galaxy. The discovery kick-started a new field, the study of molecules drifting in the interstellar medium. Bania is one of those who led the charge. "The big breakthrough in my lifetime was the whole discovery of molecules in interstellar space," he says. As of 2022, some 256 types had been found, mostly identified from the way they absorb specific wavelengths of passing radio waves. "We found this rich molecular chemistry in space," says Bania.

Some of these molecules are complex hydrocarbons. Even simple amino acids, the building blocks of proteins, have been spotted. That led astronomers to explore whether the ingredients of life could have been delivered to planets like Earth across interstellar space, either floating freely or on comets or asteroids, something that remains unanswered today. "It's a very interesting question," says Alexander Tielens at Leiden University in the Netherlands. "Did life start somewhere in the universe and spread? Or do we just have conditions everywhere that are amenable to the formation of life?"

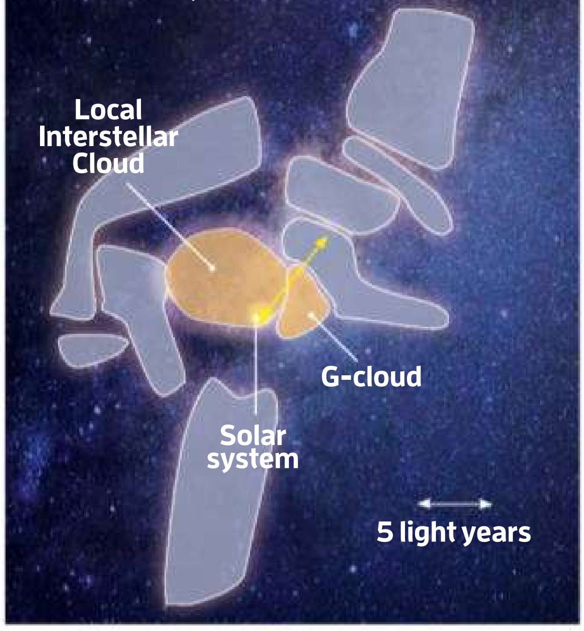
Just as interstellar space isn't empty, it isn't a still, tranquil zone either. Instead, it is like an ocean full of waves. We learned this, again, from the Voyager probes. In 2021, when Stella Koch Ocker at Cornell University in New York and her colleagues analysed data sent by Voyager 1 from beyond the heliopause, they were surprised to find waves of radio activity washing over the spacecraft. These were caused by events from the sun seeping through the heliopause and interacting with the interstellar medium. "It's really exciting," says Rankin.

Interstellar space may have waves like an ocean, but it isn't an unbroken expanse. Instead, it is divided into many bubbles, each with its own character. This was originally recognised in 1992 by astronomer Rosine Lallement at the Paris Sciences et Lettres University in France. By studying the motion of sodium gas in our corner of the galaxy, she found that the solar system was moving through a cloud of dust and gas about 10 light years across, now known as the Local Interstellar Cloud. She also realised we were heading out of that bubble and towards another one called the G-cloud (see "A new bubble", below). "It was a big moment in my career," says Lallement. Within a year, detections of the flow of interstellar helium gas by NASA's Ulysses spacecraft would support the findings.

Later work by Lallement and others using the Hubble Space Telescope has helped pinpoint our position more accurately by measuring the motion of our sun with respect to our neighbouring star system Alpha Centauri. This showed that our solar system entered the Local Interstellar Cloud about 60,000 years ago and will pass into the G-cloud in about 2000 years. In cosmic terms, we are right on the edge.

A new bubble

The solar system resides in one of several vast bubbles of interstellar space. We are speeding towards a new bubble called the G-cloud and should reach its edge in about 2000 years



What happens when we enter this new bubble? The good news is that the G-cloud appears to have a similar density to our Local Interstellar Cloud, meaning few changes. The bad news is that the character of the boundary between the clouds is uncertain. It isn't clear if they are touching or if there is an intermediary region of different density between.

If we encounter a higher density region, that could push more heavily on our heliosphere, causing it to shrink and allowing harmful cosmic rays to penetrate deeper in towards the solar system's rocky planets like Earth. That would be unwelcome. A higher flux of cosmic rays might increase Earth's cloud cover and cool our climate, and it could also cause more genetic mutations in cells as high-energy particles enter our bodies. "Earth would see the effects [of cosmic rays] much more than at present," says Jeffrey Linsky at the University of Boulder, Colorado. On the other hand, if we enter a region of lower density, the heliosphere could expand, increasing the volume of space that is shielded from cosmic rays and possibly boosting the habitability of areas at the distant edges of the solar system.

On a grander scale, our 10-light-year-wide Local Interstellar Cloud resides in a much larger, irregularly shaped structure called the Local Bubble, which is 1000 light years across.

Not all interstellar space is alike. The Veil nebula (left) is rich with gas

Engineers prepare Voyager 2 for launch in 1977 (below)

NASA/JPL-CALTECH

This is a giant shell of expanding gas formed by more than a dozen stars exploding as supernovae, with a density around a tenth that of the space outside the Local Bubble. Recent estimates have suggested that our solar system entered this bubble about 5 million years ago, and we are now roughly at its centre.

Our place in space

In another 8 million years, it is predicted we will reach its edge. In 2022, Catherine Zucker at the Space Telescope Science Institute in Maryland and her colleagues used the European Space Agency's Gaia telescope to track the motions and positions of stars in our vicinity. This showed that the centre of the Local Bubble is relatively empty, but that the edges have a much higher density of material. "We're accidentally in a great position," says Zucker.

Yet that could change as we near the edge. Ongoing work by Opher suggests the higher pressure we would experience as we near the edge of the Local Bubble would shrink the heliopause to the wrong side of Earth's orbit, exposing us to far more cosmic rays. Earth would be "in interstellar space", says Opher. It is reasonably well known that the sun will get much hotter over the next billion years, hot enough to boil Earth's oceans away. But our traverse of interstellar space could have its own serious consequences for life on Earth far sooner. "Where we were in the past and where we are going to be in the future is critical," says Opher. "I think it will have a direct effect on habitability."

We can only learn so much about interstellar space while studying it from within our solar system. That is why scientists are now proposing new missions that would surpass the work of the Voyager craft and be equipped with instruments specifically designed to study the great beyond. In the US, a proposal called Interstellar Probe is being considered by NASA, with a decision as to whether it gets funding expected by the end of 2024. This 50-year mission would launch in the 2030s and reach the heliopause in 15 years, before travelling perhaps 10 times further than the Voyager craft have. "The whole idea is to get far beyond the heliopause into the pristine interstellar medium," says Linsky, who is part of the mission's science team.

One of the key goals would be to take an image of our heliosphere – you might call it the ultimate selfie – and so deduce its shape once and for all. This would be done using an instrument designed to detect atoms from our sun hitting the interstellar medium, revealing whether it is a croissant shape like Opher expects or something else.

"Where we are heading in interstellar space will have a direct effect on habitability"

Another proposed mission, from China, called Interstellar Express and comprising two craft intended to launch later this decade, would carry similar instruments, providing views from different positions outside the solar system, giving us a better understanding of the heliosphere's shape. These missions could also directly study remnants of the supernovae that fashioned our Local Bubble, perhaps telling us when and where some of these explosions took place. "We're beginning to piece that together," says Jesse Miller at the University of Illinois Urbana-Champaign.

The interstellar medium is much more than just the gap between the stars. It is the ocean in which our sun and all the other stars in our galaxy sail. More than ever, we know where we are in this ocean. "It's kind of extraordinary," says Rankin. "We're starting to look back on ourselves from the outside now for the first time." ▮

Jonathan O'Callaghan is a science journalist based in the UK who focuses on space. You can follow him on Twitter @Astro_Jonny

An intimate transplant

Swapping your vaginal bacteria for someone else’s may sound unusual, but it could be a life-changing treatment for millions, finds **Alexandra Thompson**

“I DON’T have to be afraid someone will smell what I smell,” says Eden. “I don’t have to be afraid to be in an intimate position. Bacterial vaginosis doesn’t manage me anymore.”

Bacterial vaginosis (BV) isn’t a problem people normally talk about, despite it being the most common vaginal condition in women and girls aged 15 to 44. Caused by a change in the balance of vaginal bacteria, it produces grey, watery discharge that smells of fish. While antibiotics can treat the problem, for the vast majority of people they offer only temporary relief before the condition returns.

Now, though, there is hope. It comes in the form of a vaginal microbiome transplant (VMT). Eden was one of the first five women in the world to receive such a transplant. The idea is simple: repopulate the unbalanced bacterial environment using fluid taken from someone with a healthy vaginal microbiome.

With early signs of success, the treatment is now being trialled on a larger group of women in the US. The hope is that such trials will lead to insights that will help the millions of people around the world who have recurrent BV.

It appears the vaginal microbiome is having a moment. Scientists have recently created the “vagina on a chip” to better understand vaginal health and conditions, there is the ongoing search for “super-donors” with the perfect vaginal environment, not to mention companies offering to test your vaginal microbiome from home. But how much do we really know about this intimate community of bacteria, viruses and fungi, and should we really be swapping it with someone else’s?

Our microbiome – the microbes that live in our gut and elsewhere in and on our body – plays a crucial role in our health. Changes in our microbiome are linked with all manner of conditions, from heart disease and obesity to diarrhoea and depression.

In 1958, faecal microbiome transplants (FMTs) were trialled for the first time to treat bacterial infections. Researchers figured that if an imbalance of good and bad bacteria in the gut is behind a certain condition, then replacing it with the microbiome from someone who is healthier could solve the problem. Today, FMTs are approved in the UK and US for treating a subset of *Clostridium difficile* infections that are unresponsive to antibiotics and, in some cases, potentially deadly. Since 2012, the non-profit organisation OpenBiome has reportedly processed more than 3600 kilograms of stool, treating more than 65,000 people with *C. difficile*. A recent trial also successfully used FMTs to treat people with irritable bowel syndrome.

It wasn’t until the past decade that researchers considered doing something similar with the vaginal microbiome, which is linked to its own host of conditions, including BV, pelvic inflammatory disease, recurrent yeast infections and cancers of the reproductive tract.

BV was the first condition to be studied with VMTs in mind. It affects around 1 in 3 women and can increase the risk of sexually transmitted infections, reduce fertility and cause adverse pregnancy outcomes, including premature birth. Up to 80 per cent of those affected experience recurrent BV within nine months of the initial infection. The incidence in trans men is unknown.

Bacteria cocktail

Correcting an out-of-sorts microbiome by transplanting a cocktail of bacteria from a “healthy” vagina may sound like a simple solution. But there were immediate hurdles, not least that it quickly became apparent no one really knew what a healthy vaginal microbiome looked like.

At first glance, the vaginal microbiome appears relatively simple, as microbiomes go. In general, it has less bacterial diversity than, say, the gut. It is mostly a delicate balance of different species of the *Lactobacillus* genus. However, it becomes considerably more complex when you consider that there is no one way for a vaginal environment to be, with this ecosystem changing throughout a person’s life, during pregnancy, menopause and even on a monthly or daily basis.

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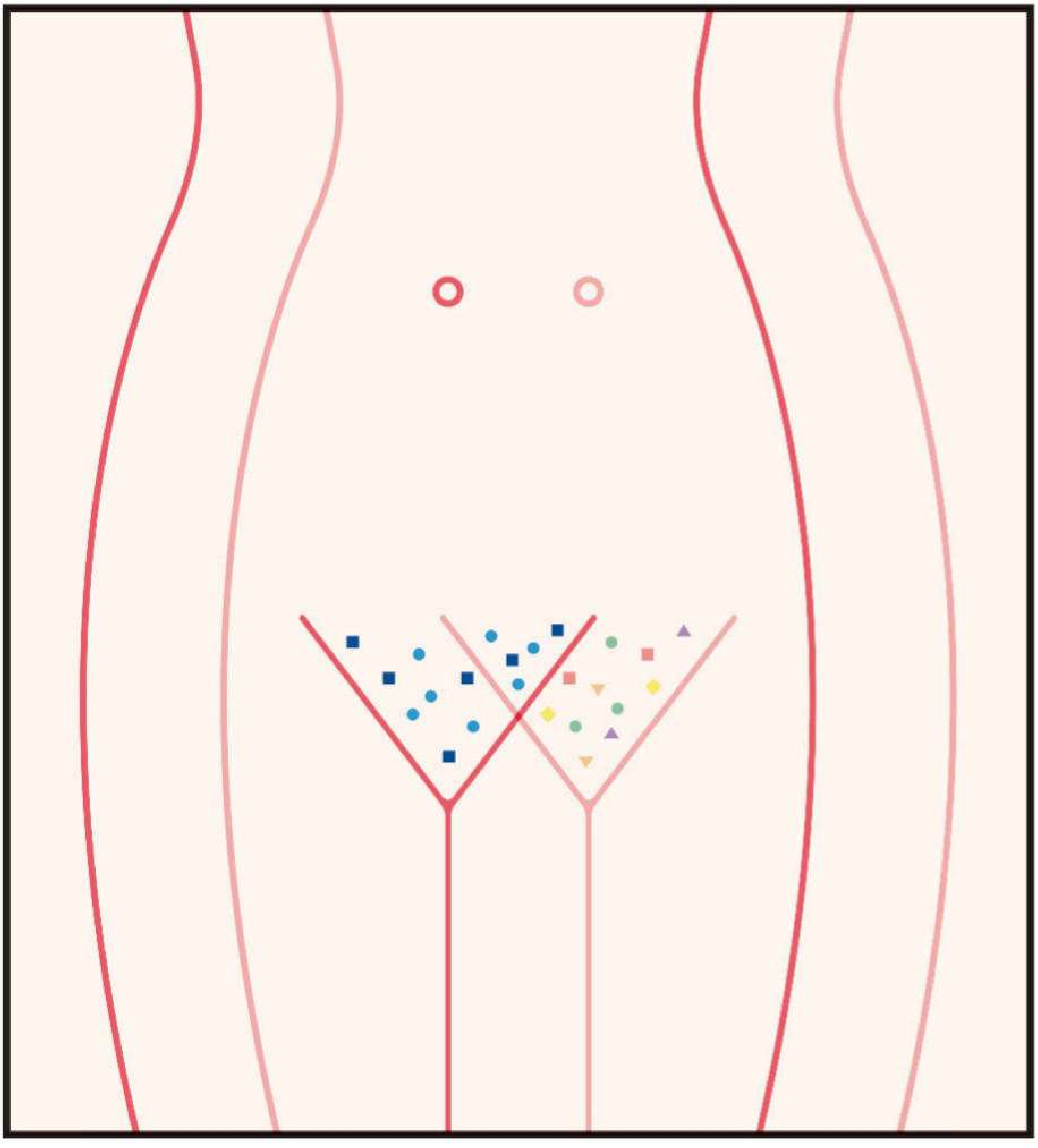


PÂTÉ

THE ETHICS OF SWAPPING BODILY FLUIDS

Both faecal and vaginal microbiome transplants come with a set of ethical considerations. In order to treat people with *Clostridium difficile*, researchers at Guy's and St Thomas' NHS Foundation Trust in London created oral capsules from donors' stools. Contributors aren't paid, only reimbursed travel costs – but given they are providing a potentially life-saving treatment, should they be?

Team leader Blair Merrick worries paying donors may encourage people to lie on the questionnaire that is part of the donor screening process. Lying about medical conditions or recent antibiotic use could raise the risk of harmful bacteria being transferred to transplant recipients, despite all stool samples being screened for pathogens pre-transfer, he says.

In Boston, Massachusetts, the campaign Poop With Purpose, run by Finch Therapeutics, has previously offered people $1500 a month to donate stool, in the hope of identifying the optimal gut microbiome. Paying people for their stool samples may disproportionately encourage donations from people with low incomes, but this isn't unethical, says Quill Kukla, an ethicist at Georgetown University, Washington DC. "Stool is a waste product we expel anyhow, and want to get rid of."

Paying for fluid samples for use in vaginal microbiome transplants poses a bigger ethical question. In trials, the fluid is extracted using a harmless but invasive procedure. Giving blood is also invasive, but donors are paid to do so in many countries.

Reimbursement aside, our bodily fluid and waste products also contain our DNA. Rigorous anonymisation systems are therefore required to protect a donor's privacy, says Kukla.

There are also ethical questions around whether people should be told if their stool or vaginal fluid reveals a medical condition they may not know about, adds Kukla.

Inevitably, this has made it hard to work out how the vaginal microbiome changes in conditions like BV. For instance, studies suggest that BV may be linked with a loss or sharp decline in certain species of *Lactobacillus*. Another bacteria, *Gardnerella vaginalis*, is nearly universally present in people with BV, but some people with *G. vaginalis* don't have symptoms, says microbiologist Gregory Buck at Virginia Commonwealth University in Richmond. "As a result, the definition of BV is difficult," says Buck. "It's a bit wishy washy."

Nevertheless, with little else to offer people with recurrent BV like Eden, Ahinoam Lev-Sagie at the Hadassah Medical Center in Jerusalem forged ahead with a pilot study of VMTs – the first of its kind.

Her team began by giving five women with recurrent BV (including Eden) antibiotics to suppress their vaginal microbiome. A week later, they collected vaginal fluid from three donors who hadn't experienced BV in the past five years, using a spatula-like device designed for cervical screening. Within the hour, each sample was diluted with saline solution. Each recipient received a portion of fluid from a single donor, just behind the cervix.

At regular follow-ups, the recipients' symptoms were checked and their vaginal fluid analysed. They were offered up to three repeat procedures if symptoms of BV returned between follow-ups. Four out of five of the women, including Eden, had no symptoms up to 21 months after their final transplant, when the study period ended. The fifth had a significant reduction in symptoms.

Broadly speaking, then, the trial was a success. But many questions remained. One of the participants only went into remission after she changed donors, for instance. What was in the second donor's microbiome that helped that wasn't in the first?

One answer may be that a healthy vaginal microbiome isn't just about the presence of one particular kind of bacteria, like certain species of *Lactobacillus*, but several working in collaboration. We know, for instance, that wiping out the unhealthy microbiota associated with BV using antibiotics doesn't encourage the growth of good bacteria, says Lev-Sagie. "It takes away the bad bacteria, but then they come back."

Likewise, administering certain species of *Lactobacillus* as an oral pill or vaginal suppository has also had limited success, with any benefits short-lived. Lev-Sagie estimates that about six to 10 different species of bacteria were transferred in the donors' fluid in her pilot trial. How many of them contributed to the final result, and which made the biggest contribution, is unknown.

Communications failure

In fact, perhaps it is wrong to give bacteria the credit at all. Vaginal fluid also contains things like skin cells, mucus, sugars, viruses, fungi, electrolytes and proteins. There are many unknowns regarding how different aspects of the vaginal environment communicate with each other and whether miscommunications can lead to medical conditions, says immunologist Eran Elinav at the Weizmann Institute of Science in Rehovot, Israel.

Lev-Sagie and her colleagues are now recruiting 100 women with BV to take part in a larger trial to find some answers. A similar trial of 134 women with BV is also under way at Massachusetts General Hospital. Trans men who aren't on hormone therapy and who haven't had gender-confirming surgery are also eligible to join. In both trials, the groups will be split, with one half receiving a transplant from

MAGDALENA IORDACHE/AGEFOTOSTOCK/ALAMY

Vaginal douching can lead to health problems and isn't recommended by doctors

donors with “healthy” levels of *Lactobacillus* and the other half receiving a placebo.

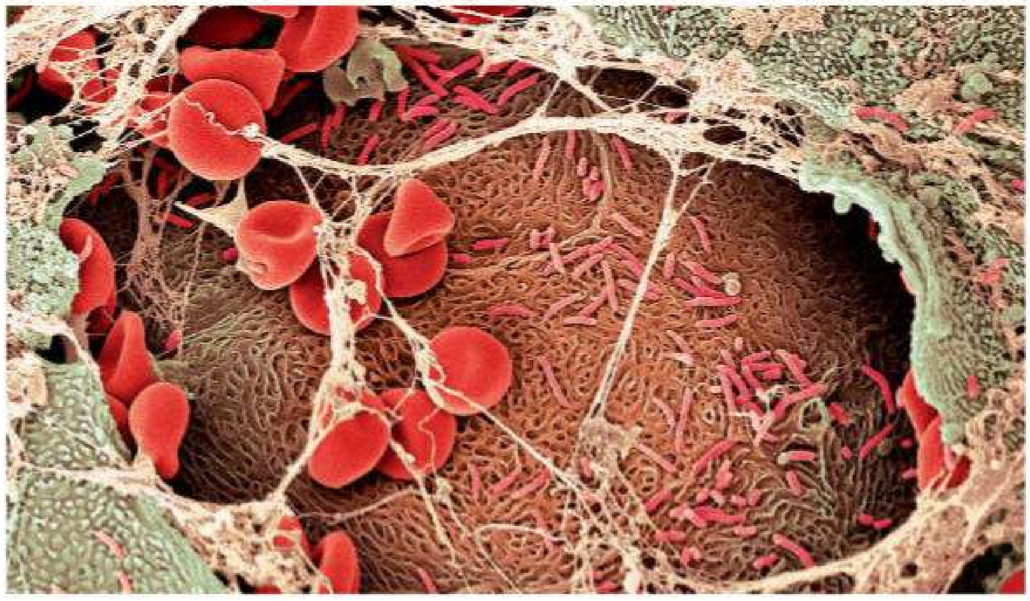
Identifying exactly what works and why won’t be easy. Not only does the vaginal microbiome change during pregnancy, the menstrual cycle and menopause, sex, vaginal douching (washing the inside of the vagina), applying perfumed products to the vulva and using intrauterine contraceptive devices can also throw things out of whack. “We see daily fluctuations,” says Lev-Sagie. We can somewhat control for these factors in trials, for example by not taking donations during pregnancy or asking recipients to abstain from sex before the study. But these frequent changes are part of the reason why the vaginal microbiome has remained unexplored for so long.

Differences in the vaginal microbiome have also been associated with ethnicity. These differences could come down to things such as genetics, access to healthcare or variations in diet. “The jury is still out,” says Elinav.

Nevertheless, inroads into understanding the vaginal microbiome are being made. Don Ingber’s team at Harvard University has recently developed a “vagina on a chip”. This silicone chip contains vaginal tissue that is washed with a hormone-filled fluid. It is responsive to fluctuating hormone levels and bacteria – mimicking the real vaginal environment. By changing the tissue sample and the fluid contents, the chip could make it easier to understand how different people’s vaginal microbiomes change in different environments and to test new treatments.

> “There are hopes of finding a super-donor whose vaginal microbiome is top class”

Then there are hopes that trials may identify “super-donors”, whose vaginal fluid is top class, who could right the microbial wrongs of a wide range of people with BV. However, with VMT trials few and far between, identifying a super-donor – whose fluid would have to prove its worth by treating a large number of recipients – will take time. Not everyone is convinced it is even possible. Getting healthy bacteria to colonise a vagina isn’t a slam dunk, says Bunk. You need precise conditions and what these are is still an open question.


STEVE GSCHMEISSNER/SCIENCE PHOTO LIBRARY

Infection can be caused by bacteria on the vaginal wall

Of course, as with any transplant, there are questions over the safety – and ethics – of VMTs (see “The ethics of swapping bodily fluids”, left). Donors are screened to make sure they have no sexually transmitted infections or unusual bacteria present. They are given a gynaecological examination and complete a medical questionnaire. Lev-Sagie is confident that the vaginal fluid they transfer is safe, and no side effects were experienced by any of the five participants in her pilot trial. But some researchers worry that screening isn’t enough. In rare cases, dangerous bacteria have inadvertently been transferred from seemingly healthy donors to recipients during FMTs, says Buck. “Even though we have pretty good ways to determine what is in a sample, we really can’t guarantee what’s in it.”

A solution could be to create a lab-made cocktail containing only the “right” bacteria. Lev-Sagie hopes her larger study will identify the key bacteria that could be used in an at-home probiotic treatment. But such a product may be some way off. “The vaginal microbiome is complicated. How long will it take to produce, in a clean way, the components that are crucial to cure different vaginal conditions?” says Maria Gloria Dominguez-Bello at Rutgers University in New Jersey.

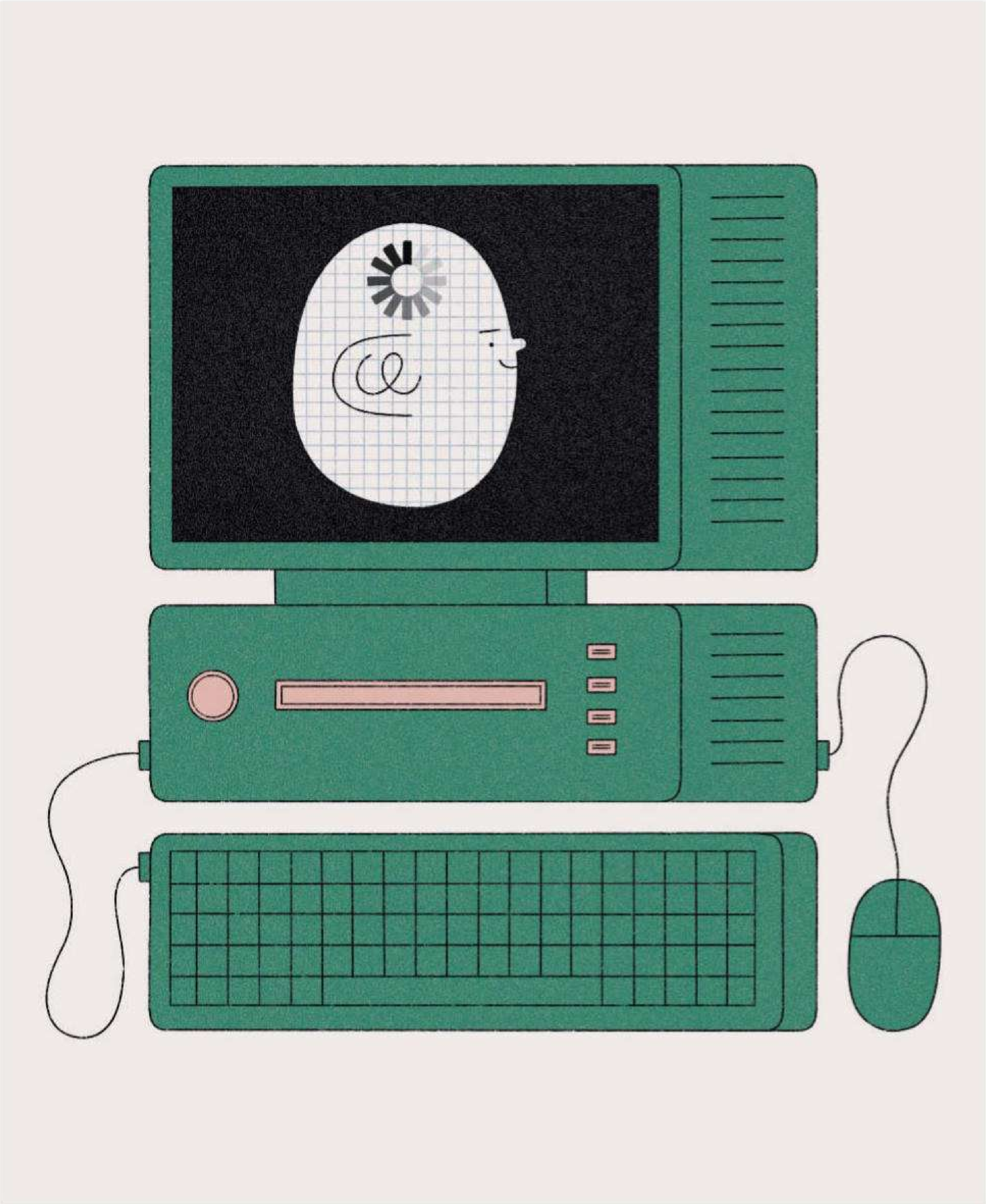
Given the uncertainties around what a healthy vaginal microbiome looks like, it may come as a surprise to hear that companies such as Juno Bio in London are offering to give you insights into your own, using a simple at-home test kit. A swab from the vagina is sent to their labs and your microbial DNA is analysed. The firm sends you a report with what bacteria are present, what they are known to do and what effect they might have on your health.

“They will tell you your microbial profile, but so what? What are you going to do with it?” says Dominguez-Bello. Even if you are told you have a profile that resembles those with BV, if you are asymptomatic, the information may be redundant, she says. Juno Bio didn’t reply to *New Scientist*’s requests for comment.

What is clear is that there are still a lot of hurdles before we really get to grips with the vaginal microbiome or how to tweak it to our advantage, but also that the new interest has great potential to help a vast number of people. “Adjusting the microbiome is a huge question,” says Elinav. “We’re just starting to scrape the surface of how we could alter these very complex microbial communities.”

For Eden, the mere attempt to do so was “life changing”. Now the vaginal microbiome is finally getting the attention it deserves, the next few years may see thousands more people experience the same reaction. ▮

Alexandra Thompson is an assistant news editor at *New Scientist*



HOLLIE FULLER

Machine mind readers

For artificial intelligence to become truly useful, we need it to know what we're thinking. But how, asks **Edd Gent**

SUPERHUMAN artificial intelligence is already among us. Well, sort of. When it comes to playing games like chess and Go, or solving difficult scientific challenges like predicting protein structures, computers are well ahead of us. But we have one superpower they aren't even close to mastering: mind reading.

Humans have an uncanny ability to deduce the goals, desires and beliefs of others, a crucial skill that means we can anticipate other people's actions and the consequences of our own. Reading minds comes so easily to us, though, that we often don't think to spell out what we want. If AIs are to become truly useful in everyday life – to collaborate effectively with us or, in the case of self-driving cars, to understand that a child might run into the road after a bouncing ball – they need to establish similar intuitive abilities.

The trouble is that doing so is far harder than training a chess grandmaster. It involves dealing with the uncertainties of human behaviour and requires flexible thinking, which AIs have typically struggled with. But recent developments, including a game-playing AI that learned to cooperate with humans and AIs that can succeed at hide-and-seek, show that socially savvy machines aren't a pipe dream. What's more, thinking about others could be a step towards a grander goal – AI with self-awareness.

"If we want robots, or AI in general, to integrate into our lives in a seamless way, then we have to figure this out," says Hod Lipson at Columbia University, New York. "We have to give them this gift that evolution has given us to read other people's minds."

Psychologists refer to the ability to infer another's mental state as theory of mind. In humans, this capacity starts to develop at a very young age, says Alison Gopnik at the University of California, Berkeley. By the age of 9 months, babies understand that people's actions are linked to their goals. Between 18 months and 2 years, they start to grasp that each person's goals can be different because we have unique desires.

At around 4, they pass the "false belief test". This involves a child watching someone place an object, which is then moved without that person's knowledge. The child is then asked where the other person will look first, and getting this right requires them to understand that the other person has different, and false, beliefs. Remarkably, by the age of about 5, humans have a fairly sophisticated ability to infer what others are thinking, says Gopnik.

People aren't the only mind readers. Some animals also seem to display varying degrees of theory of mind. Chimpanzees, bonobos and orangutans are all capable of passing the false belief test, and birds including ravens and jays are also capable of inferring others' mental states.

How to reproduce these capabilities in machines is far from clear, though. Part of the problem is that what we describe as theory of mind is, in fact, not just one thing. "There are so many elements to what people call theory of mind," says Bertram Malle at Brown University, Rhode Island. "It's a large collection of abilities." At the simpler end of the spectrum is the capacity to understand the motivations behind actions, whereas at the other extreme is the kind of complicated social manoeuvring you get in a Jane Austen novel.

One of the main challenges is context, says Julian Jara-Ettinger at Yale University. For instance, if someone asks if you are going for a run and you reply "it's raining", they can quickly deduce that the answer is no. But this requires huge amounts of background knowledge about running, weather and human preferences.

When it comes to teaching AIs these skills, it make sense to start simple, says Malle, especially as it seems that there is a some kind of hierarchy to theory of mind skills. "Some capacities are just more frequent in the animal world, appear much earlier in human development and probably have lower complexity," he says.

Yet even the simplest social skills are far from trivial to translate into machines. The kind of calculations involved are quite different from the formulaic logic that computers normally use. Most importantly, › they need to be able to deal with uncertainty, says Samuel Kaski at the University of Manchester, UK.

A person's internal mental processes are impossible to observe directly, so the best you can do is make informed guesses based on the evidence available. Doing so typically involves flipping a classic machine learning technique called reinforcement learning on its head. In its conventional form, this involves setting an AI a goal and rewarding it for taking actions that work towards that goal. Through trial and error, the agent learns behaviours that achieve the goal. "Inverse reinforcement learning" works the other way round: observing someone's actions over time and using this to build up a picture of what that person is trying to achieve. This is similar to a child watching a game of hide-and-seek for the first time and quickly deducing what the goals of the different players are.

A popular way to do inverse reinforcement learning relies on a statistical technique called Bayesian inference. This lets you analyse new data while taking into account prior knowledge. The technique is powerful, says Kaski, because it deals well with uncertainty and lets you make use of what you already know about a problem as well as adapting to new information as it becomes available.

In 2022, Kaski and his colleague Sebastiaan De Peuter used Bayesian approaches to develop a prototype digital assistant that could help someone solve problems that require making a series of interrelated decisions. In this case, the AI helped someone plan a weekend sightseeing trip based on their budget, time constraints and preferences. The example might seem trivial, but Kaski says it is fundamentally similar to helping solve more complex tasks like engineering design, and his goal is to develop AI assistants that accelerate the work of scientists and doctors. "The motivation really comes from being able to solve harder problems better," he says.

Most research on machine theory of mind to date has relied on simplified scenarios, such as inferring the goals of agents moving around in basic two-dimensional grid worlds. But Josh Tenenbaum at the Massachusetts Institute of Technology is trying to bring these techniques into the real world. In 2020, his group combined Bayesian approaches with a programming language used by robots, which he says could ultimately help apply these techniques to practical robotics challenges. More recently, they upped the complexity of the task into three dimensions.

One of the key ways to test theory of mind in infants, says Tenenbaum, is to show them videos of people and then quiz the children about what the people are trying to achieve, and his team wanted to try this with AIs. In 2021, Tenenbaum and his colleagues unveiled a new challenge in which AI agents watch 3D animations of cartoon characters running up ramps, jumping over walls and going through doors. Their Bayesian model got close to human-level prediction in several scenarios.

PETER MENZEL/SCIENCE PHOTO LIBRARY

Machines that infer what we are thinking could cooperate better

ANUP SHAH/NATUREPL.COM

Orangutans can pass a "false belief" test, as can some AIs

While it is still early days, Tenenbaum says his team is working with researchers at Microsoft, IBM and Google who are interested in applying their ideas to real products . "We are far from having a complete model of theory of mind," he says. "But we have enough of the building blocks that actually, with engineering scale, it could already be quite useful in a range of applications."

Other researchers are taking a fundamentally different approach to this problem. Most of the headline-grabbing AI developments in recent years have relied on deep-learning neural networks, a family of algorithms loosely inspired by the brain. A key feature is that programmers build very little prior knowledge into these systems, instead allowing them to learn from experience by ingesting mountains of data.

This is the approach taken by researchers at Google-owned DeepMind to develop their so-called Theory of Mind-net, or ToM-net for short. In 2018, they showed that ToM-net could pass a false belief test, when the researchers hid or moved objects other agents were searching for in a two-dimensional grid world. Since then, others have applied similar ideas to more complex domains.

A key milestone in children's development

“This is another significant step on the path to socially savvy AIs”

of theory of mind is understanding that people’s point of view can differ from their own, says Lipson. For instance, children under the age of 4 often try to hide by closing their eyes, assuming that if they can’t see you, you can’t see them. So, in 2019, Lipson and his colleagues challenged a deep-learning AI to a game of hide-and-seek. They created a 3D simulation dotted with obstacles and dropped in two agents, a predator and a prey, whose only information came from their first-person view of the environment.

The seeker was governed by a set of rules designed to help it hunt out the other agent and the hider was governed by a neural network that, over many trial rounds, successfully learned how to hide. To solve the challenge, the hider had to see the world through the seeker’s eyes, says Lipson. “I think that’s the root of theory of mind,” he adds. “To be able to actually visually see the world from another person’s perspective, not just think about it logically.”

In 2021, Lipson and his colleagues extended their approach, showing that an AI trained on thousands of images of a robot carrying out simple activities could learn to guess what its plans were with 99 per cent accuracy. It even passed a false belief test when the researchers hid one of the robot’s objectives.

Understanding intentions

A key motivation of Lipson’s approach is that he wants theory of mind to emerge spontaneously from the learning process. Building prior knowledge into AI makes it reliant on our imperfect understanding of theory of mind, he says. In addition, AI may be capable of developing approaches we could never imagine. “There can be many forms of theory of mind that I don’t know about simply because I live in a human body that has certain types of senses and a certain ability to think,” says Lipson.

But fresh results from researchers at Meta suggest a combination of approaches might be a powerful way to reproduce some of the capabilities involved in theory of mind. In November, they unveiled an AI called Cicero that learned to play the board game Diplomacy, which sees up to seven people fighting to conquer Europe. Before each round, players get a chance to negotiate and form alliances. This is highly challenging for AIs, as it requires both effective communication and predicting other players’ intentions to work out how to cooperate.

REAL444/GETTY IMAGES

Advanced social skills are needed to understand hide-and-seek

The team solved this challenge by linking a deep-learning language model that can interpret and generate messages with a strategic planning model that learned the game by playing copies of itself. Crucially, the planning model relied on concepts from game theory, which uses mathematical models to understand strategic decision making. Cicero trained on data from real Diplomacy games to predict what players will do based on the state of the board and previous dialogue. This was then fed into the planning model, which comes up with a strategy balancing the theoretically optimal moves for all players against what their messages suggest they will do. Cicero then generates messages to help it achieve its goals. In an online league, it ranked in the top 10 per cent without raising suspicions that it was an AI.

Noam Brown, one of the lead researchers, says the team decided against using the term theory of mind to avoid getting bogged down in semantics, but he believes their work makes fundamental contributions. “A rose by any other name,” he says. “It’s really the substance that matters, and I think that the substance of what we’re doing is understanding the beliefs, goals and intentions of the other players.”

This is another significant step on the path to socially savvy machines. But Cicero’s ability to model players’ mental processes still falls short of true theory of mind, says Tenenbaum, because the models are highly specific to Diplomacy and can’t be repurposed for other tasks. “They seem to have acquired some strategies that reflect what humans do using theory of mind, but that’s not the same as saying that they’ve acquired a theory of mind.”

That might seem like splitting hairs, but there are practical reasons why we might want AI to have a more human-like form of theory of mind , says Tenenbaum. Deep-learning systems are typically black boxes – it is hard to decipher how exactly they came to a decision. Humans, on the other hand, can clearly explain their goals and desires to each other using common language and ideas. While learning-based approaches are likely to play an important role in developing more potent AIs, says Tenenbaum, explicitly building in shared ways to represent knowledge may be crucial for humans to trust and communicate with AI.

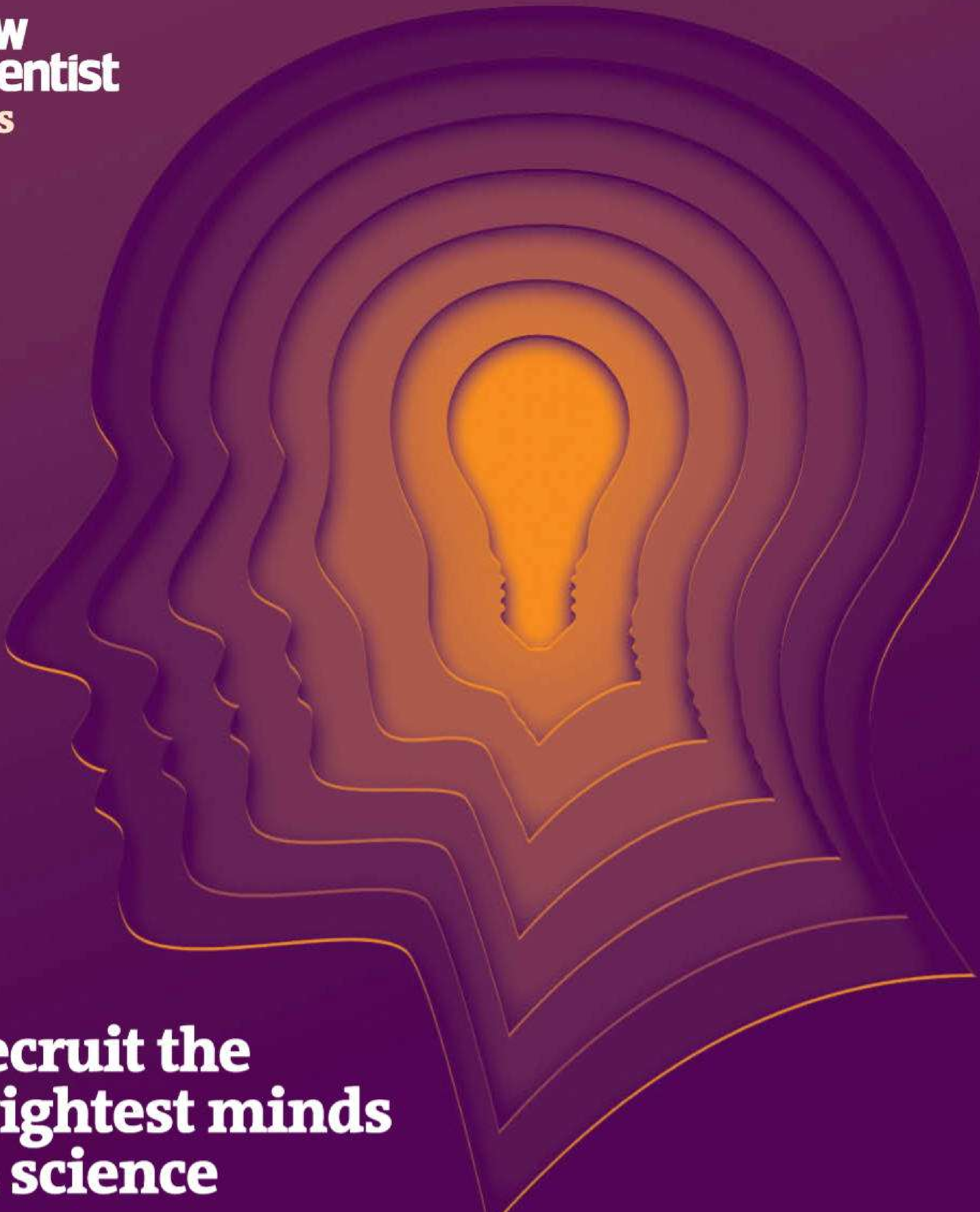
“There should be a fundamental human-likeness to them, which I don’t think you’re going to get if you just go about the route of building a big data set and doing a lot of machine learning on it,” says Tenenbaum. This will also be critical if we want to use AI to help us better understand how theory of mind works for us too, he adds.

It is important to remember, though, that the quest to imbue machines with theory of mind is about more than just building more useful robots, says Lipson. It is also a stepping stone on the path towards a deeper goal for AI and robotics research: building truly sentient machines. “The most fascinating thing about theory of mind is that it’s on the path towards self-awareness and consciousness,” says Lipson. “Thinking about other people and other agents is on the path to learning to think about yourself.”

Whether we will ever get there remains to be seen. But perhaps, along the way, we will learn something about ourselves too. ■

Edd Gent is a freelance writer based in Bangalore, India, who focuses on emerging technology

New Scientist
Jobs



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Citizen science

A day by the sea

You can contribute to a global map of ocean microplastic pollution by collecting samples on your local beach, finds **Layal Liverpool**

Layal Liverpool is a science journalist based in Berlin. She believes everyone can be a scientist, including you. @layallivs

KONRAD WERYS

I AM visiting my hometown of The Hague on the west coast of the Netherlands and I have decided to take my family on a fun trip to the seaside. When I say "fun trip", I of course mean an excursion to collect samples for my latest scientific research endeavour: the Big Microplastic Survey.

This project involves sampling sediment along a 30-metre stretch of beach from within five quadrants, each 1 square metre in size, and filtering it to extract any microplastic or mesoplastic fragments – pieces of plastic 1 to 5 millimetres or 5 to 25mm across, respectively. Any such fragments are then sorted by type and colour, photographed and submitted to the survey as observations via an online form.

Data gathered by volunteers contributes to a global map of microplastic pollution, including the density of the pollution and the proportions of various types of plastic found in different regions. The Big Microplastic Survey began in 2018 and is run by charity Just One Ocean and the University of Portsmouth in the UK, but you can participate anywhere in the world.

On the beach in The Hague, unfazed by the icy North Sea breeze, my family and I choose our sampling area and use a maps app on one of our phones to record our location. Later, we will use this to share the coordinates of our position so that our findings can be added to the Big Microplastic Survey's global results map.

If you decide to conduct your own survey, it is recommended that you do so during an outgoing tide, as this is the safest time to survey and the best time for locating strandlines – regions where previous high tides have deposited seaweed and other ocean debris. The ideal strandline to sample along is the highest one, also known as the wrack line. More detailed instructions on how to conduct your own survey are available via the project's website.

Regardless of whether you discover zero fragments or hundreds of them (my family and I found just one microplastic fragment in our survey), your observations contribute valuable information. Hundreds of people across 55 countries have participated in the survey since it launched and their findings are helping to uncover sources of microplastic pollution around the world.

Results so far show that although there is regional variation in the types of microplastic fragments collected by volunteers, the majority identified globally are nurdles – small pellets used in plastic production.

David Jones, CEO of Just One Ocean, hopes the data gathered through the survey will help to inform government policies aimed at tackling microplastic pollution, which threatens the environment and potentially also human health. ▮

What you need

To register for the Big Microplastic Survey at microplasticsurvey.org.
Access to the seaside and a 30m stretch of beach.
Rope or thick string at least 4m long for mapping out sampling areas.
A 10cm quadrant cut out of cardboard to guide sampling.
A spoon for digging up sediment.
Two buckets and a 1mm mesh sieve for filtering microplastic fragments.
A takeaway food tray or other container for storing collected material.

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Next week

Science of cooking

These articles are posted each week at newscientist.com/maker

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Characterization of Dark Energy and Derivation of Hubble's Constant Using Harmonic Quintessence

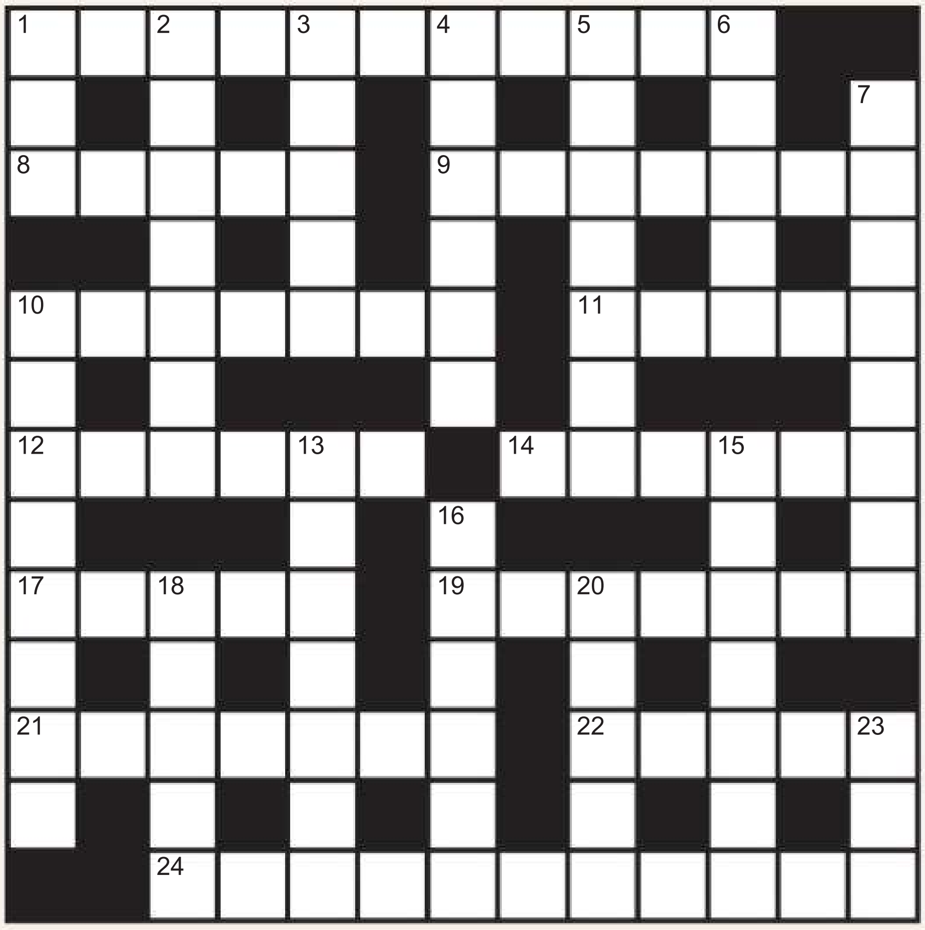
Abstract

In this paper, using harmonic quintessence, it is shown that the fundamental parameterization of dark energy can be determined using Planck's constant. This allows the derivation of the mass density, and in turn we obtain the energy density of dark energy. This characterization of dark energy also allows the derivation of an averaged value of Hubble's constant, which is in keeping with results from the Planck telescope. This establishes the fundamental element of the Universe, derived from Planck's constant, as Harmonic Quintessence. It is also possible to confirm the vacuum electric permittivity, magnetic permeability and the field equations for dark energy and corroborate the continued expansion of the Universe. This establishes the fundamental element of the Universe, derived from Planck's constant, as Harmonic Quintessence.

Scan the QR code below to read the full paper

https://doi.org/10.5539/apr.v14n2p29

Cryptic crossword #103 *Set by Rasa*



Scribble zone

Answers and the next quick crossword next week

ACROSS

1 Tellurium coated in copper? Uncertain (11)
8 Remove condensation from forged abstract right away (5)
9 Desert-like condition across free, leaderless metropolis (7)
10 Care awfully about that male organism with multiple genotypes (7)
11 River sound that's soothing guards outside of Netherthong (5)
12 Repetitive noises from HR suppressed by antacids (6)
14 Common profile pic files corrupted by malware, finally (6)
17 Norwegian-born chemist Onsager grabs Kelvin for more than one 20 Down (5)
19 Include liquid deuterium, for example (7)
21 Fellows at university pursuing westbound transit vehicle options (7)
22 Almost tear after favourite German microbiologist (5)
24 Reportedly, paving material breaks down tiny animals (11)

DOWN

1 Something to chew on is oddly clued (3)
2 Above level, shark's appendage flipped cooler (7)
3 Sea gleam camouflages predator (5)
4 Emperor and Indian prince in Tennessee (6)
5 Zest atop revolutionary eggy bread (7)
6 Send up unsophisticated Perrier rival (5)
7 Mineral beasts of burden brought into flammable heap (8)
10 At last Cy synthesised rate-controlling substance (8)
13 Widespread regret upset spa worker (7)
15 Passed out trendy clogs in store (7)
16 Invalidate marriage over essentially unsized rings (6)
18 Mug rests on hollowed out assembly-line device (5)
20 Garnish something one might cut? (5)
23 Extremely remote lab exists near pole (3)

Our crosswords are now solvable online
newscientist.com/crosswords

Quick quiz #189

set by Bethan Ackerley

1 The Hayflick limit is the number of times that certain cells can do what?

2 In cosmology, inflation is theorised to have begun approximately how soon after the big bang: 10^{-3600} seconds, 10^{-360} seconds or 10^{-36} seconds?

3 In which group of animals would you find the rumen, the reticulum, the omasum and the abomasum?

4 Who wrote the environmental science book *Silent Spring*, sparking a movement that led to a US-wide ban of the insecticide DDT?

5 In what year did Marie Curie win her first Nobel prize?

Answers on page 55

Puzzle

set by Maslanka

#209 Postman's knock

There was a knock at Professor Numero's door. It was a postal worker.

"Excuse me disturbing you, but can you help? This letter has a cryptic address. I can't make head or tail of it:

"To the Resident,
The house with a number whose digits when multiplied together give five times what they sum to,
Long Road"

The professor pondered. "Well, you've come to the right road. And, luckily, there's only one house number in the road with this mathematical property – the one at the end, where Colonel Crypto lives."

As you would expect, the houses in Long Road are numbered consecutively from 1 upwards, with no missing numbers. How many houses are there in the road?

Solution next week

Shout it out

When doing strenuous exercise such as weightlifting, it seems to help to call out the number of repetitions. Why?

Penny Jackson
Barrow-in-Furness, Cumbria, UK
When doing strength training, I was taught that it is important to breathe (presumably in order to ensure the muscles are getting a good supply of oxygen). Talking is a good way of forcing yourself to breathe. Talking about something else may cause you to lose count of the number of repetitions, so counting them out loud is ideal.

If you have never done that sort of strenuous exercise, the idea of forgetting to breathe may sound surprising, but it does seem to be a problem.

Arvind Joshi
Mumbai, India
There appear to be many advantages to calling out the number of repetitions during exercise: it keeps the mind occupied, serves as positive feedback to motivate a person to reach their target number of repetitions and gives a sort of rhythm to the exercise.

> **"By calling out the repetitions, you can achieve increased core stability without having to consciously think about it"**

But the greatest advantage is that it helps avoid a common problem experienced by people during strenuous exercise: the tendency to hold breath during exertion, which results in reduced blood supply to the body.

Oliver Arditi
Stoke-by-Nayland, Suffolk, UK
For me, shouting out the number of repetitions helps because, if I don't, I forget how many reps I have done, compelling me to continue indefinitely.

CLARKANDCOMPANY/GETY IMAGES

In its raw state, rhubarb isn't appetising, so how did it come to be used as a food?

This week's new questions

In bad taste **How was rhubarb found to be edible? It certainly isn't palatable raw.** ***Donald Windsor****, Norwich, New York, US*

Candle in the wind **Flames go out when their oxygen supply is cut off, so what is happening when you blow a candle out?** ***Pauline Fothergill****, Pocklington, East Yorkshire, UK*

David Muir
Edinburgh, UK
When you forcibly exhale, you actively contract the muscles of the abdominal wall. This increases engagement of your core muscles, and a tight core equates to more power and stability in strength training. By calling out the number of exercise repetitions, this effect can be achieved without consciously thinking about it.

Don't be too loud, though, as other gym users may be irritated.

Simon Dales
Oxford, UK
Counting a known number of repetitions has two benefits: regulation and psychology.

When weightlifting, the higher the load, the fewer the reps that can be done – but each one should be the same. Knowing the number helps regulate power.

Counting yourself maintains agency, which is psychologically easier than if the count is "inflicted" by someone else.

Super tug

I am fascinated by the idea of a tug of war between Dover, UK, and Calais, France, with thousands of people on each side, 42 kilometres apart. Could a rope be made long, light and strong enough for this?

Martin Gellender
Brisbane, Australia
The maximum distance that can be spanned by a rope or cable is limited by it sagging under its own weight.

Near the centre of the span, the cable will only be slightly curved and tensile force within the cable will be nearly constant. But away from the centre, the upwards slope of the cable becomes steeper and the tensile force increases.

The sag of the cable can be reduced by increasing the tensile force – by pulling harder at the ends – but only up to the tensile strength of the material. The tensile stress could be reduced by increasing the thickness of the cable, but this adds to its weight, so there is still a maximum span.

I calculate that the maximum distance that can be spanned by a steel cable with a tensile strength of 1000 megapascals is 40 kilometres. So, a tug of war with such a cable across a distance of 42 km would be impossible. The maximum span could be increased by using materials that are lighter and stronger than steel, such as titanium alloys, although such materials tend to be much more expensive than steel and more difficult to fabricate.

Eric Kvaalen
Les Essarts-le-Roi, France
The problem is that the rope would go down into the water unless the tension were many times its weight.

A rope made of the synthetic fibre Kevlar, for instance, can support about 250 kilometres of itself if held vertically. But in the tug of war, it would be in the form of a catenary (a rope suspended between two points at the same height). Even if the people on the English side are standing on top of the cliffs of Dover, a Kevlar rope would be too weak to keep itself from touching the water.

Garry Trethewey
Cherryville, South Australia
This tug of war would be possible via the Channel Tunnel. It would also be possible with a rope floating on the sea – though this might entail other problems.

In round figures, let's say there are 10,000 people on each side,

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Tom Gauld
for New Scientist

MAYBE THE REAL GOLD WAS THE FRIENDSHIPS WE MADE ALONG THE WAY!
PALCHEMISTS

each weighing 100 kilograms. Let's also say that each can lean back 45 degrees before they slip, and so they can each pull with 100 kg of force.

Functionally, the number on one side would act like an anchor to the number on the other side, so we wouldn't have to count all 20,000 people, just the ones on the side where the anchor fails. We now have 10,000 × 100 kg, or 1000 tonnes, pulling on the rope.

If it were made from Dyneema, which is very strong and so light that it floats, I calculate that a rope with a 1000-tonne breaking strain would have to be 120 millimetres in diameter. But this would only be good for a normal "face-to-face" tug of war. Next we need to factor in a 42-kilometre separation.

Would the friction from 42 km of rope make a difference? In a tunnel, yes. This rope would weigh just under 300 tonnes and there would be some friction between the rope and the tunnel floor. How much? It is hard to put numbers to this, but imagine dragging a rope along the ground. Tested on my floor, my lawn and some rough ground, the force needed to drag the rope is less than the weight of the rope. With Dyneema being fairly slippery and the floor of the tunnel being smooth, this comes in at less than the 300 tonnes, so wouldn't materially alter the situation. If, alternatively, our tunnel were 4200 km long, the rope would weigh 30,000 tonnes and neither side could move it.

If the rope were floated across the channel in still water, friction would be nil, but a strong tide might drag the rope and pull both teams into the water.

"If the rope for a tug of war floated on the sea between France and England, a strong tide might pull both teams into the water"

Original me

I am 65. Assuming that I still weigh what I did at 25 (I wish!), what percentage of material from 40 years ago remains as part of me today? (continued)

Tobias Bast
School of Psychology, University of Nottingham, UK

I wanted to pick up on a previous response to this question, which suggested that neurons in our brains are continuously replaced and an 80-year-old would retain virtually no neurons from their 20-year-old brain.

The formation of new neurons in adult brains, known as adult neurogenesis, is well established in many animal species, although evidence for it in humans is somewhat controversial. Regardless, this process is limited to a few brain regions, including a small subregion of the hippocampus. Also, adult neurogenesis adds neurons to the existing network, rather than replacing them. Therefore, it is very likely that the majority of the neurons in your 65-year-old (or even in your 80-year-old) brain will be the same as those you had at 25 years old, or even at 20.

Answers

Quick quiz #189
Answers

1 Divide
2 10^{-36} seconds
3 In ruminants – they are the four sections of their stomach
4 Rachel Carson
5 1903

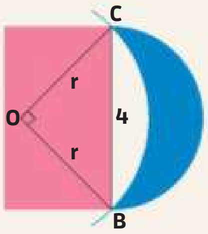
Quick crossword #126 *Answers*

ACROSS 8 Dalton, **9** Rambutan, **10** Zoom, **11** Ylang-ylang, **12** Zinc, **13** On the blink, **17** Yeti, **18** Agent, **19** NASA, **21** Researcher, **23** Emit, **24** Micrometer, **28** Data, **29** Cocobolo, **30** Switch

DOWN 1 Masonite, **2** Atomic pile, **3** Ankylosaur, **4** Orca, **5** Smog, **6** Hull, **7** Tannin, **14** Teeth, **15** Enterprise, **16** Linseed oil, **20** Sciatica, **22** Edison, **25** Root, **26** Moon, **27** Troy

#208 Flower power
Solution

The blue and pink areas are the same, 16 square metres.



OBC is a right-angled triangle, so $OB^2 + OC^2 = CB^2$, $2r^2 = 4^2$, $r^2 = 8$. The area of triangle OBC = 4 square metres. The area of circle quadrant OBC = $\frac{1}{4}\pi r^2 = \frac{1}{4}\pi \times 8 = 2\pi$. The area of the clear segment is the area of the quadrant less the area of the triangle = $2\pi - 4$. The area of the blue crescent is the area of the semicircle minus the area of the segment = $\frac{1}{2} \times 4\pi - (2\pi - 4) = 4$ square metres. As this is the same as the area of the triangle, the four crescents together have the same area as the central square.

A sticky fix

News headlines tell a gripping, simple tale: "Royal Navy probe after claims £88m Trident submarine nuclear reactor fault was fixed with super glue" (Wales Online). "Furious Navy chiefs order investigation after 'workers on Trident submarine glued broken bolts in a nuclear reactor chamber'" (*Daily Mail*). "Engineers Use Superglue To Repair Broken Nuclear Submarine: 'Disturbing' And 'Insulting'" (International Business Times).

The Guardian **quotes a UK navy source as saying: "It's a disgrace. You can't cut corners with nuclear. Standards are standards. Nuclear standards are never compromised." But of course you can, and they are.**

The British navy has a history of money-saving innovation. The 2000 Ig Nobel Peace Prize was awarded to the Royal Navy for ordering its sailors to stop using live cannon shells, and to instead just shout: "Bang!" Invitations to the navy to participate in the Ig Nobel ceremony got lost in a sea of naval bureaucracy. Nobel laureate Richard Roberts, who helped present the prizes that year, accepted temporary custody of the navy's trophy. Roberts has still, these 23 years later, not managed to find a navy official who will officially take the prize on board.

Twisteddoodles *for New Scientist*

USING TAGGING, WE DISCOVERED THAT THE MATING PAIRS STAY TOGETHER FOR LIFE.
THOSE SCIENTISTS PUT RINGS ON US BOTH, SO I GUESS THAT MEANS WE'RE MARRIED NOW?
HA! I'M YOUR WIFE FOR LIFE. SUCKER!
@twisteddoodles

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A coffee a day

The word "could" carries a lot of water (so to speak) that could be used to brew a lot of coffee (so to drink) in a US study called "Benefit-Risk of Coffee Consumption and All-Cause Mortality: A Systematic Review and Disability Adjusted Life Year Analysis". The study enlivens the sometimes death-centric journal *Food and Chemical Toxicology*.

The authors begin by saying: "Recommendations and guidance from scientific bodies do not provide clear messages about potential health risks or benefits of coffee consumption." They proceed to brew and serve a clear message. Attention focuses on the study's impressive special ingredient: computed statistics called "disability-adjusted life years [DALYs]".

Things do go on to get a little complicated, but the basic theme is almost transparent. In the US, "More than 3.5 million DALYs, or approximately 3.35% of estimated years of healthy life lost could be prevented by consuming one cup of coffee per day". The study adds that even more estimated years of healthy life lost could be not lost "if consumers all drank 3 cups of coffee per day".

The paper's final paragraph offers a caffeine-joltish fillip of joy for readers who are habituated to scouring mystery stories for exciting clues: "The authors are all employed by ToxStrategies, a consulting firm… ToxStrategies received consulting fees from the National Coffee Association".

Alternatively, people can benefit from making cups of coffee without drinking them. In 2006, Tokyo Denki University researchers asked six right-handed young men to use their left hand to make coffee. The resulting study is called "Eye-hand Coordination in Development of a Natural Task: Making ten cups of coffee". It reports that, by the ninth cup, most of the off-hand baristas had measurably improved their eye-hand coordination.

Wipe without whining

A new study in the journal *Applied Acoustics* includes an intellectual treat: a short history of humanity's attempt to grasp and solve a small, annoying problem. The specific issue: when a windscreen-wiper changes direction, it makes a noise.

Xue Yang and colleagues at Shanghai University of Engineering Science report two kinds of good news. Firstly, they have made headway on the windscreen-wiper direction-reversal frictional-vibration problem: "It is concluded that properly reducing the length of blade tip is an effective way to reduce vibrations of the system." More importantly, they see this as groundwork for future progress.

Yang's team dutifully tells of previous efforts to overcome windscreen wiper harshness. In Japan, researchers tried to discern a general "mechanism of wiper blade rubber squeal noise generation", while a South Korean effort investigated "squeal noise generation due to windscreen waviness". A group in France established, as a theory, "a single degree-of-freedom link model of the wiper blade and explained the evolution process of instability by using the Stribeck's friction law". At least one scientist sought an explanation arising from chaos.

Those investigations looked strictly at what happens as a blade traverses glass in a single direction. The noise problems that happen when a wiper blade changes direction have their own history of attempts and advancements – a history quietly growing as we watch and listen.

CSI: Gorham

Fiction overflows with police officers who use good scientific technique to solve mysteries and journalists who use clear, terse prose to inform the public. Carmen Nobel reminds Feedback that such people do exist. The *Gorham Times*, in Gorham, Maine, features "the blotter", a summary of incidents as noted by local law enforcement. The 19 January edition tells an entire detective story in just 35 words: "Osborne Road caller was concerned because she found what she believed to be a suspicious footprint on her property. Officer compared the footprint to the bottom of her shoe and it was an exact match." ▮

Marc Abrahams

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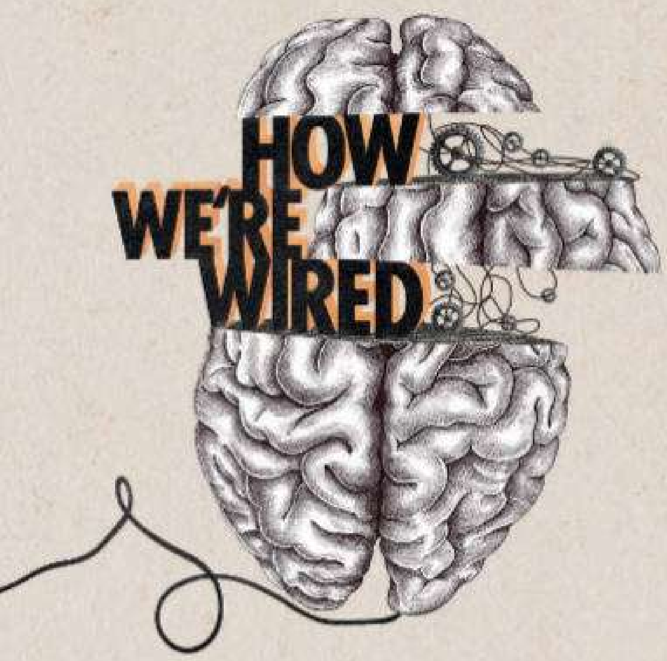

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